AIDS TO CHEMISTRY

INORGANIC PART I

NON-METALLIC ELEMENTS

ARMAND SEMPLE

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BALLIERE, TINDALL & COX

AIDS
TO
CHEMISTRY.

SPECIALLY DESIGNED FOR
STUDENTS PREPARING FOR EXAMINATIONS.

PART I.—INORGANIC:
THE NON-METALLIC ELEMENTS.

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PREFACE.

THE last Edition of these "Aids to Chemistry" was subjected to such careful revision that very few alterations have been rendered necessary in the preparation of this, the Fifth Edition. It has, however, been considered expedient to introduce a few more equations, and to supply some additional explanatory matter.

The original scheme has still been retained, viz. : the explanation of every symbol wherever it occurs.

The present volume is only intended as an introduction to the study of chemistry; and I would draw attention, for a more extended knowledge of the subject, to the excellent works of Fownes, Miller, Attfield, and Roscoe.

ARMAND SEMPLE.

8, TORRINGTON SQUARE,
March, 1881.

THE NON-METALLIC ELEMENTS.

Oxygen.	Chlorine.
Hydrogen.	Bromine.
Nitrogen.	Iodine.
Carbon.	Fluorine.

Sulphur.
Phosphorus.
Arsenicum.
Boron.
Silicon.
Selenium.
Tellurium.

INTRODUCTION.

CHEMISTRY is the science which investigates the nature and properties of all the bodies composing the universe. It demonstrates the actions exerted between the atoms and molecules of bodies, and the forces by which combination takes place.

Chemistry divides all bodies into SIMPLE and COMPOUND. To the simple bodies the name of ELEMENTS is applied; some of these are *gaseous*, two are *liquid*, and the remainder *solid*. The elements are divided into the NON-METALLIC ELEMENTS and the METALS, although it is possible there may be no real distinction between them. That part of chemistry which refers to bodies which are not the products of life, belongs to the province of INORGANIC CHEMISTRY, whereas all those substances which exist in living bodies, or are formed by the agency of living bodies, belong to the province of ORGANIC CHEMISTRY.

Certain characters termed symbols are employed for representing the elementary substances in formulæ and equations. By a symbol not only is the substance specified represented, but also a definite amount of that element, *i.e.*, its *atomic weight* or combining proportion. O represents oxygen, but it also indicates that there are 16 parts of it in the compound; if there are any more parts in it, this fact is denoted by the addition of a little figure termed *the co-efficient*, which is placed immediately under the symbol, thus, O_2, O_3, implying that the 16 is multiplied twice or thrice; and as will be seen hereafter, it is a fundamental law in chemistry that all substances unite in only one proportion, or in multiples of that proportion.

Oxygen unites only in quantities which are represented by the figures 16, 32, 48, 64, &c., or multiples of 16, and nitrogen in the multiples of 14, its atomic weight, viz.: 14, 28, 42, 56, &c.

The density of a gaseous substance, is as a rule identical with its combining weight; thus, the combining weight of oxygen is 16, and its density is 16; the combining weight

of nitrogen is 14, and its density is 14, and so of other gases. But an exception to this rule is observed in the case of phosphorus and arsenic, for, as will be hereafter explained, the vapour densities of these two bodies are double their combining weights.

The density of a compound body is obtained by halving the molecular weight; thus, the molecular weight of carbonic oxide, CO, is 28, and its density is therefore 14.

The term *chemical combination* indicates the union of two or more bodies to form a third, differing entirely from the original substances, whereas *mechanical mixture* simply denotes that the substances are merely mixed together; thus, the action of iodine upon metallic mercury to form the green iodide of mercury is an instance of chemical combination; and the mixture of gases in atmospheric air is illustrative of mechanical mixture.

Chemical affinity, or chemical attraction, implies that peculiar force by which a certain element or group of elements will attach itself to another to form a new substance.

Elective affinity is the attraction of one substance for another to the exclusion of a third.

Until the end of the year 1877 the four gases, hydrogen, oxygen, nitrogen, and nitric oxide had never been liquefied; but at this period two experimenters, named Pictet and Chailletet, of Geneva, succeeded, with enormous pressure and intense cold, in reducing these to a liquid form. They also at the same time liquefied atmospheric air.

Every known gaseous body has now been reduced to a liquid.

When it is stated that a gas was liquefied by a pressure of so many atmospheres, it is meant that the number of atmospheres is multiplied by 15. Thus oxygen was liquefied by a pressure of 300 atmospheres, *i.e.*, 300 × 15 (15lbs. being the pressure upon every square inch of the earth's surface), or 4500lbs. Degrees of frost denote so many degrees below the freezing point.

AIDS TO CHEMISTRY.

OXYGEN (oxus, acid, genesis, a generator).

Symbol, O. Combining weight, 16. Density, 16.

Description.—A gas; colourless, inodorous, invisible, and tasteless. Slightly soluble in water. The great supporter of combustion, and most magnetic of gases. Specific gravity is 1·1056, the specific gravity of air being 1. A dyad element, replacing two monads as in the case of water, $\left.\begin{matrix}H\\H\end{matrix}\right\}O$. Necessary to respiration, decay, germination, and putrefaction. Discovered by Scheele and Priestley, independently, in 1774, and liquefied in 1877 by a pressure of 300 atmospheres and 65 degrees of frost. When oxygen is inhaled in excess, death is produced by over-stimulation.

Sources.—Exists free in the atmosphere, of which it constitutes one-fifth by bulk, and combining with almost all organic bodies and most minerals, forms nearly half by weight of the solid earth. Fluorine is remarkable for forming no compound with this gas. Eight-ninths by weight of water consists of oxygen.

Preparation.—(1.) By heating red mercuric oxide (HgO);

$$HgO + \text{heat} = Hg + O.$$

Metallic mercury remains at the bottom of the vessel, and oxygen is given off, and is collected over water.

(2) By heating chlorate of potash ($KClO_3$);

$$KClO_3 + \text{heat} = KCl + O_3.$$

Chloride of potassium and oxygen are formed.

(3) By heating manganese dioxide, otherwise called black oxide of manganese (MnO_2).

$$3MnO_2 + \text{heat} = MnO, Mn_2O_3 + O_2.$$

The black oxide is decomposed into the red mangano-manganic oxide and oxygen.

(4) By mixing a small quantity of black oxide of manganese with the chlorate of potash, it is found that the oxygen is given off at a much lower temperature from the chlorate, and thus the evolution of the gas is facilitated, while the manganese dioxide does not undergo the slightest change.

(5) By electrolysis from water (H_2O), the oxygen separating at the platinode or positive pole.

(6) By heating strong sulphuric acid (H_2SO_4) with manganese dioxide;

$$MnO_2 + H_2SO_4 = MnSO_4 + H_2O + O.$$

Sulphate of manganese, water, and oxygen are formed.

(7) Oxygen is set free by the action of sunlight upon the carbonic acid (CO_2) contained in the chlorophyll, or green colouring matter of plants. The plant retains the carbon (C) for its growth, the oxygen being set free for the support of the respiration of animals.

Tests.—(1) A *glowing* chip of wood plunged into the gas immediately *bursts into flame.*

(2) Sulphur, which burns with a pale blue flame in air, emits a *bright violet light* in oxygen.

(3) Phosphorus inflamed and placed in this gas exhibits *dazzling brilliancy.*

(4) By tipping a bundle of fine iron wire, or a steel watch-spring, with burning sulphur or glowing amadou (a spongy substance), and placing it in a jar of oxygen, *showers of splendid scintillations* are produced, oxide of iron dropping in the molten state to the bottom of the jar.

OZONE—O_3O—(ozein, to emit an odour).

Description.—An allotropic modification of oxygen; may be termed *condensed* oxygen, since it is found that this substance is one and a-half times as heavy as O, *i.e.*, three volumes of oxygen condense to form two volumes of ozone. It is a gas of a peculiar, strongly oppressive odour which is perceptible during the working of an electrical machine; possesses great bleaching and disinfecting properties, corrodes india-rubber, and is completely soluble in oil of turpentine. Discovered by Schönbein in 1840.

Preparation.—(1) By passing a series of electric sparks through air or through oxygen.

(2) By allowing a stick of phosphorus to hang in a bottle filled with *moist* air.

(3) By the electrolytic decomposition of water, in which small quantities of ozone are produced.

(4) By heating strong sulphuric acid (H_2SO_4) with permanganate of potash ($KMnO_4$) thus—

$$2KMnO_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 3H_2O + 2O + O_2O.$$

Sulphate of potash, sulphate of manganese, water, oxygen, and ozone are produced.

Tests.—(1) Sets iodine (I) free from iodide of potassium (KI), hence paper impregnated with starch and iodide of potassium is turned blue by ozone;

$$6KI + 3H_2O + O_2O = 6I + 6KHO.$$

Iodide of potassium, water, and ozone give free iodine and liquor potassæ.

(2) Converts protosalts of manganese into persalts, and sulphite of lead into sulphate.

HYDROGEN—(hudor, water, genesis, a generator).

Symbol, H. Combining weight, 1. Density, 1.

Description.—A gas; colourless, invisible, tasteless, and inodorous. The lightest body known, being 14·47 times lighter than air. Very slightly soluble in water. The specific gravity, air being taken as the unit, is 0·0693. Discovered by Cavendish in 1766, and liquefied in 1878 by a pressure of 650 atmospheres and 140 degrees of frost. When hydrogen is inspired the voice is rendered puerile.

A monad element, and the standard of atomic weights.

Sources.—Chiefly found in combination; with oxygen in water, of which it forms one-ninth by weight, and in nearly all organic bodies.

Preparation.—(1) From water (H_2O) by metallic potassium (K). Thus—

$$K + H_2O = KHO + H.$$

A solution of potash and hydrogen are formed.

(2) By passing steam over red-hot iron (Fe) in a gun barrel. Thus—

$$4H_2O + 3Fe = Fe_3O_4 + 8H.$$

Ferrous-ferric oxide (Fe_3O_4) remains.

(3) From diluted sulphuric acid (H_2SO_4,H_2O) and zinc (Zn). Thus—

$$H_2SO_4,H_2O + Zn = ZnSO_4 + H_2O + 2H.$$

Sulphate of zinc remaining.

(4) By electrolysis of water, hydrogen separating at the negative pole or zincode.

This gas may be readily collected over water.

Test.—Hydrogen is not a supporter of combustion, but a combustible body. This can be shown by placing a lighted taper in a jar of the gas; the flame of the taper is *extinguished*, but another flame is observed at the mouth of the jar; this is of a very pale blue colour, possesses little luminosity, but intense heat, and is produced by the *combustion* of the hydrogen, the result being a few drops of water.

HYDROGEN WITH OXYGEN forms two compounds:

(1) Hydrogen monoxide, or, water ... H_2O.
(2) Hydrogen dioxide ... ... H_2O_2.

HYDROGEN MONOXIDE (H_2O). WATER.

It is found that when hydrogen burns in air, water is formed by its union with oxygen. In 1781, Cavendish showed that two volumes of hydrogen unite with one volume of oxygen to form water. He made a mixture in this proportion in a jar, and then passed the gases into a strong vessel furnished with a stop-cock from which the air had been pumped out. An electric spark was passed through two platinum wires melted through the glass; an explosion followed, dew was seen to be deposited upon the sides of the vessel, and upon opening the stop-cock under water, this liquid rushed in and completely filled the whole space originally occupied by the mixed gases. The glass was weighed before and after the explosion, and the weight of the glass being known, the weight of the water produced was the same as that of the gases which combined.

The composition of water is determined in two ways:—

(1) By SYNTHESIS
(2) By ANALYSIS.

SYNTHESIS, or the placing together of the ingredients, is performed in the following manner:—a long, accurately graduated, glass tube, called a *Eudiometer* is taken. This is open at one end and closed at the other, and through the top of the closed end are melted two platinum wires. The tube is filled with mercury, and then inverted, open end downwards, over a trough filled with the same metal. Hydrogen is admitted into the tube, and the volume measured (say 100 volumes); oxygen is then allowed to enter (say 75 volumes), and the volume of the two mixed gases is measured. An electric spark is now passed through the gases by means of the platinum wires; a flame passes down through the gas, showing that combination has occurred, and the water produced is deposited as dew upon the inside of the tube; this will only

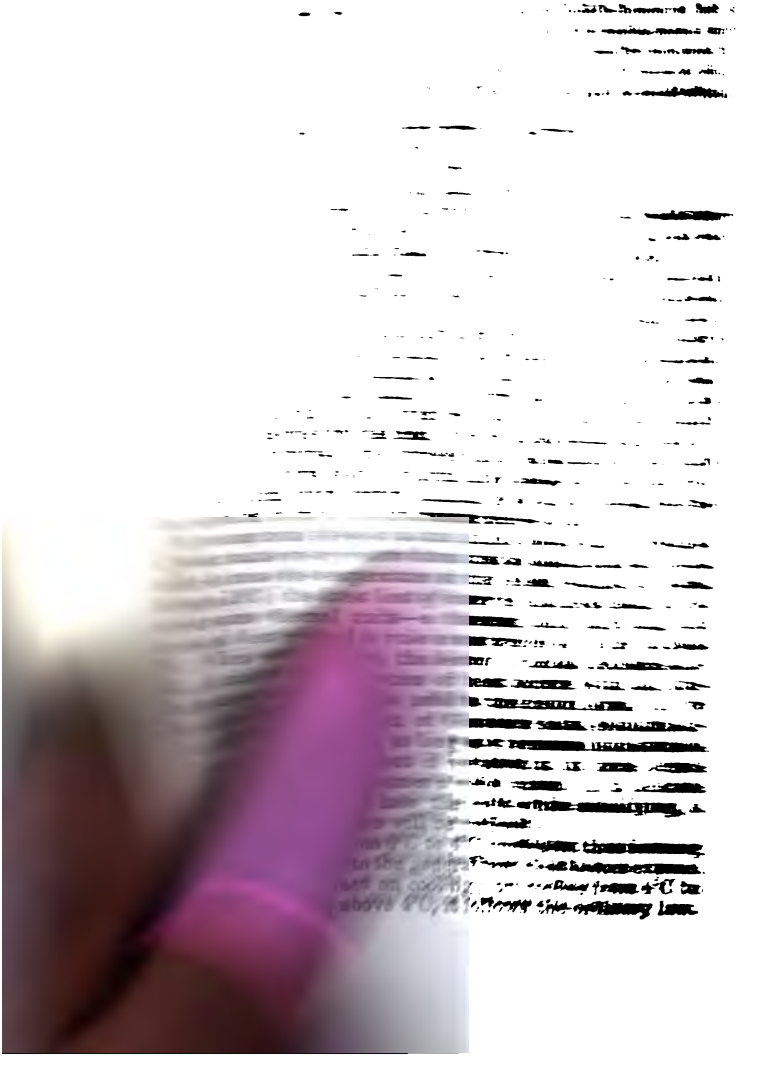
occupy about $\frac{1}{2000}$ part of the bulk of the constituent gases, so its volume may be neglected. Upon opening the bottom of the eudiometer, the mercury in the tube rises, and we find that only 25 volumes of gas remain, which turns out to be pure oxygen. Thus, 100 volumes of hydrogen require exactly 50 volumes of oxygen for their complete combustion. By a modification of this experiment, it can be shown that the volume of gaseous water occupies exactly 100 volumes; or, two volumes of H unite with one volume of O to form two volumes of steam; hence density of steam or weight of one volume is

$$\frac{16 + 2}{2} = 9$$

ANALYSIS, or the splitting up into the constituents, is performed as follows:—A glass vessel is filled with water, acidulated with sulphuric acid, to assist the conduction of electricity; two test tubes, also filled with water, are then inverted into this vessel over two small platinum plates attached to wires passing through a caoutchouc stopper at the bottom of the glass. On connecting the plates with the terminals of a galvanic battery, an evolution of gas from each is observed; that disengaged from the plate in connection with the *platinum end* of the battery is found to be *pure oxygen*, while that from the plate in connection with the *zinc end* is *pure hydrogen*. If the tubes be graduated, the volume of the hydrogen is found to be a very little more than double that of the oxygen, for since O is rather more soluble than H, we do not get quite the exact proportions. Oxygen being sixteen times as heavy as hydrogen, and these gases combining to form water in the proportions, by volume, of one of the former to two of the latter, we thus know that the proportions by weight in which these gases exist in water must be as sixteen to two.

Free O and H combine together, when a light is applied, with such force that a dangerous explosion occurs from the sudden expansion caused by the great heat evolved. If a soda-water bottle be filled one-third full of O, and two-thirds with H, and a flame applied to the mouth, the gases combine with a sudden detonation like the report of a pistol.

The *oxyhydrogen blowpipe* is employed to develop the great heat evolved by the combination of the two gases. These, which should be in the proportions to form water, *i.e.*, two vols. of H to one vol. of O, are contained separately in two caoutchouc bags, and are only brought together at the point where combination is desired, thus avoiding the danger of explosion.



Thus we say that the *point of maximum density of water* is 4°C; *i.e.*, a given bulk of water will weigh more at this temperature than at any other. The amount of contraction on heating is but small (one volume of water at 4°C becoming 1 + 0·00012 at 0°C), yet its influence in nature is most important. Were it not for this circumstance our climate would be arctic. In the freezing of large lakes and rivers, the cold winds gradually cool the surface-water which, becoming heavier, sinks, and lighter and warmer water rises to its place. This process goes on until the temperature of the whole mass is reduced to 4°C, and then the surface-water no longer sinks, since it is always lighter than the deeper water at 4°C. Ice is formed only at the top, the mass of water retaining a temperature of 4°C. If water became heavier as it cooled down to the freezing point, a continual circulation would be kept up until the mass was cooled to 0°C, when solidification of the whole would take place. Sea-water rarely, if ever, freezes *en masse*, on account of the great depth of water which prevents the whole being cooled down to the freezing point.

When water is heated to 100°C, it enters into ebullition, *i.e.*, steam is disengaged from the most heated surface. During this process, a large quantity of heat becomes latent, and the *latent heat of steam is said to be* 536 *thermal units*. When water thus passes into the gaseous or vaporous state, heat is absorbed, and so much heat may be thus abstracted from water, that we may cause it to freeze by its own evaporation.

Water, without entering into ebullition, possesses the power of rising in vapour at all temperatures, and this power is called the *elastic force* or *tension* of aqueous vapour.

Again, *water boils when the tension of its vapour is equal to the superincumbent atmospheric pressure*. On the tops of mountains water boils at a temperature below 100°C, because the atmospheric pressure is less than at the sea level.

To obtain *pure* water, we are obliged to *distil* river or spring water; that is, we boil the water and collect the fluid formed by the condensation of the steam produced. Thus the solid matters are left behind. Rain water is the purest form of water in nature, but even this may contain foreign matters. Sea-water contains about thirty-five parts of solid matter (twenty-eight parts consisting of sodium chloride or common salt) in solution, in 1000 parts of water. Most salts are more or less soluble in water, and crystallise upon the evaporation of the fluid. The solubility of salts is generally greater in hot water than in cold.

Water unites with bodies to form *Hydrates;* thus we have hydrate of lime (CaO,H_2O), hydrate of oxide of copper (CuO, H_2O).

Water of Crystallisation, is the water which is necessary for the preservation of the crystalline form of certain salts, and, upon the driving off of which by heat, the crystals fall to powder. The amount of this water varies in different cases:

Thus we have

Sulphate of iron ...	... $FeSO_4 + 7H_2O$.
Sulphate of copper ...	... $CuSO_4 + 5H_2O$.
Ferrocyanide of potassium	... $K_4FeCy_6 + 3H_2O$.
Borax	... $Na_2B_4O_7 = 10H_2O$.
Alum	... $NH_4Al(SO_4)_2 + 12H_2O$.

If a saline compound absorb water from the atmosphere, it is termed *Deliquescent,* as acetate of potash ($KC_2H_3O_2$); if under the same circumstances it loses water, it is called *Efflorescent,* as in the case of phosphate of soda ($Na_2HPO_4 + 12H_2O$). A salt which undergoes no change upon exposure to air is termed *Permanent.*

Hydrogen Dioxide (H_2O_2). Hydroxyl.

Description and properties.—A liquid of syrupy consistence, and very unstable; does not occur in nature. Possesses powerful oxidising properties, bleaches a solution of litmus, and has a somewhat metallic taste. A drop placed upon the tongue blanches it, and destroys sensation for a time. It has of late years been used as a test for bloodstains, since with freshly-prepared tincture of guaiacum and blood it strikes a blue colour. Discovered by Thénard in 1818.

Preparation.—(1.) From barium dioxide (BaO_2) and hydrochloric acid (HCl)

$$BaO_2 + 2HCl = BaCl_2 + H_2O_2.$$

Barium chloride and hydrogen dioxide are formed.

(2.) By passing carbonic anhydride (CO_2) through barium dioxide (BaO_2) suspended in water—

$$BaO_2 + H_2O + CO_2 = BaCO_3 + H_2O_2.$$

Barium carbonate separates out as a white powder, insoluble in water, and H_2O_2 remains in solution; upon bringing this substance into contact with ozone, common oxygen and water are produced. If silver oxide be brought in contact with H_2O_2, metallic silver is produced, together with water and common oxygen.

NITROGEN (nitron, nitre, genesis, a generator).

Symbol, N. Combining weight, 14. Density, 14.

Description.—A gas; properties, negative; viz.: colourless,

tasteless, inodorous, neither supporting combustion nor combustible; not poisonous; animals placed in nitrogen die from oxygen starvation, hence the name *Azote* (a, privative, zoe, life), by which it is sometimes designated. Slightly lighter than air. Specific gravity, 0·972, air being 1·0. A triad element replacing three monads,

as in the case of ammonia, $N\left\{\begin{matrix}H\\H.\\H\end{matrix}\right.$ Does not readily combine with other bodies. Discovered by Rutherford in 1772. Liquefied in 1878 by a pressure of 200 atmospheres.

Sources.—Exists free in the atmosphere, of which it constitutes four-fifths by bulk; occurs in combination in the bodies of animals, in many plants, and in chemical compounds, as nitre (nitrate of potash, KNO_3), whence its name (nitre generator). Also in some mineral waters.

Preparation.—(1.) By burning phosphorus (P) in a bell-jar filled with air, the mouth of which is placed in a vessel full of water; white fumes at first fill the jar, consisting of phosphorus pentoxide (P_2O_5), and as these subside and dissolve in the water beneath, the nitrogen is left nearly pure.

(2) By passing air over red-hot metallic copper (Cu); cupric oxide (CuO) is formed, and nitrogen is set free.

(3) By passing chlorine (Cl) through *excess* of ammonia (NH_3). Thus—

$$6Cl + 2NH_3 = 6HCl + 2N.$$

Hydrochloric acid remains in solution, and nitrogen is given off. If the chlorine be in excess, a most explosive oily compound is formed, called chloride of nitrogen (NCl_3 ?).

(4) By heating the nitrite of ammonium (NH_4NO_2). Thus—

$$NH_4NO_2 + \text{heat} = 2H_2O + 2N.$$

Nitrogen with Hydrogen forms Ammonia.

Symbol, NH_3. Molecular weight, 17. Density, 8·5.

Description.—The only (separable) compound of N with H. A gas; colourless, irrespirable, with the odour of "hartshorn"; lighter than air, specific gravity 0·59 (air = 1). The volatile alkali; very soluble in H_2O, which dissolves 700 times its own volume at 0°C. Both liquefiable and solidifiable.

Sources and preparations.—Is produced in decay, and in combustion, where bodies contain N and H, and to some extent in respiration. Chiefly obtained from the decomposition of animal and vegetable matters containing nitrogen and hydrogen, either at the ordinary temperature or by the in-

fluence of heat. By heating horns, clipping of hides, or coal, ammonia is given off, hence it is known (in the first mode) as *spirits of hartshorn*. A compound called Sal-ammoniac (NH_4Cl), or chloride of ammonium, was first prepared by the Arabs by heating camels' dung in the deserts of Libya, near the Temple of Jupiter Ammon (whence the name ammonia). The dried excrement of sea-birds (guano) and the urine of animals contain considerable quantities of NH_3.

The great source of ammonia and its compounds at the present time is the ammoniacal liquor of the gas-works. The mode of preparation is the following:—

(*a*) Hydrochloric acid (HCl) is added to the ammoniacal liquor, forming chloride of ammonium (NH_3HCl); to this

(*b*) Slaked lime (CaH_2O_2) is added. Thus—

$$2NH_3HCl + CaH_2O_2 = CaCl_2 + 2H_2O + 2NH_3.$$

Ammonia may also be prepared by the action of nitric acid (HNO_3) upon metallic zinc (Zn). Thus—

$$9HNO_3 + 4Zn = 4(Zn2NO_3) + 3H_2O + NH_3.$$

The gas may be collected by displacement, the neck of the receiver being turned downwards, or it may be collected over mercury, but not over water, on account of its extreme solubility.

Tests.—(1) Possesses a strong *alkaline* reaction.

(2) Its solution turns red vegetable colours *blue*.

(3) Gives *white fumes* when placed near any mineral acid, such as nitric (HNO_3), hydrochloric (HCl), or sulphuric (H_2SO_4).

The most striking reactions are

(4) The *deep sapphire blue* colour produced when an *excess* of liquor ammoniæ is added to a solution of a salt of *copper*, and

(5) The *white* precipitate of hydrargyrum ammoniatum (NH_2HgCl) when liquor ammoniæ is added to corrosive sublimate ($HgCl_2$).

COMPOUNDS OF NITROGEN WITH OXYGEN.

Five in number, viz:

(1) *Nitrogen monoxide, nitrous oxide, or laughing gas,* N_2O.
(2) *Nitrogen dioxide, or nitric oxide,* NO or N_2O_2.
(3) *Nitrogen trioxide, or nitrous anhydride,* N_2O_3.
(4) *Nitrogen tetroxide, or hyponitric acid,* NO_2 or N_2O_4.
(5) *Nitrogen pentoxide, or nitric anhydride,* N_2O_5.

Here we have a striking instance of the *law of chemical combination in multiple proportion.*

In these compounds the O is in the proportion of the numbers 1, 2, 3, 4, 5 to one and the same quantity of N. While 28 parts by weight of N, combined with 16 of O, form 44

parts of nitrogen monoxide, we see that any other compounds of those elements contain some simple multiple of 16 parts by weight of O, either 2 × 16, 3 × 16, 4 × 16, or 5 × 16, and that no compounds exist containing any *intermediate quantity* of O.

N and O do not *readily* combine together, but they may be made to do so under certain circumstances. Suppose a series of electric sparks to be passed through a vessel full of dry air, *red coloured vapours* having a *peculiar acrid smell* are soon noticed; these consist of *tri- and tetr- oxides of nitrogen.* They have the power, like ozone, of liberating iodine from potassium iodide, and can thus be made to colour starch *blue.*

Nitrogen Monoxide. Nitrous Oxide.

Symbol, N_2O. Molecular weight, 44. Density, 22.

Description.—A gas; colourless, inodorous, with a slightly sweetish taste. Respirable for a time, and somewhat soluble in water. Supports combustion nearly as well as oxygen. Specific gravity (air being 1) is 1·527. Has been liquefied by a pressure of 50 atmospheres. Discovered by Priestley in 1785.

Preparation.—(1) By heating ammonium nitrate (NH_4NO_3). Thus—

$$NH_4NO_3 + \text{heat} = 2H_2O + N_2O.$$

(2) By the action of metallic zinc (Zn) upon diluted nitric acid (HNO_3). Thus—

$$10HNO_3 + 4Zn + H_2O = 4Zn2NO_3 + 6H_2O + N_2O.$$

Nitrate of zinc, water, and nitrous oxide are formed.

This gas is best collected over *warm* water, since it is absorbed by cold water. When intended for respiration, it must be passed through a solution of potash, and then through ferrous sulphate.

Tests.—(1) A glowing chip of wood plunged into nitrous oxide is *rekindled,* burning with a brighter flame than in air.

(2) Phosphorus burns in this gas with nearly as bright a light as in oxygen.

(3) The *feeble* flame of sulphur is extinguished, but when *burning strongly* yields a *bright light.*

(4) When *inhaled,* a peculiar *exhilarating effect* is produced, hence the name "laughing gas."

Nitrogen Dioxide. Nitric Oxide.

Symbol, N_2O_2 or NO. Molecular weight, 30. Density, 15.

Description and Tests.—A gas; colourless, and irrespirable; does not easily support combustion (ignited phosphorus, unless burning brightly, being extinguished on being placed in nitric

oxide). In contact with oxygen it immediately forms red fumes, consisting of the higher oxides of nitrogen. Specific gravity (air being 1) is 1·038. Has been liquefied by a pressure of 146 atmospheres and 16 degrees of frost.

* *Preparation.*—(1) By the action of nitric acid (HNO_3) upon copper turnings (Cu). Thus—

$$3Cu + 8HNO_3 = 3(Cu2NO_3) + 4H_2O + N_2O_2.$$

Nitrate of copper, water, and nitric oxide are formed.

(2) By nitric acid upon metallic bismuth (Bi). Thus—

$$2Bi + 8HNO_3 = 2Bi3NO_3 + 4H_2O + N_2O_2.$$

Nitrate of bismuth, water, and nitric oxide are formed.

Nitrogen Trioxide. Nitrous Anhydride.

Symbol, N_2O_3. Molecular weight, 76. Density, 38.

Description and Tests.—A gas, of *an orange red colour* at ordinary temperatures, but at -18°C a *blue* volatile liquid, emitting a red and irritating vapour. With water (ice-cold) it forms *nitrous acid* (HNO_2). Thus—

$$N_2O_3 + H_2O = H_2N_2O_4 \text{ or } 2HNO_2.$$

(HNO_2 is a very unstable blue liquid, decomposing, when the water is warmed, into nitric acid and nitric oxide. Thus—

$$3HNO_2 = H_2O + N_2O_2 + HNO_3.)$$

Nitrous acid gives rise to salts called *nitrites.* Thus, with ammonia, we have (NH_4NO_2) *nitrite of ammonia.*

Preparation.—(1) By mixing 4 volumes of dry N_2O_3 with 1 volume of O, and cooling the mixture to -18°C.

(2) By the action of nitric acid (HNO_3) and H_2O upon arsenious anhydride (As_2O_3). Thus—

$$As_2O_3 + 2HNO_3 + 2H_2O = 2H_3AsO_4 + N_2O_2.$$

Arsenic acid and nitrogen trioxide are formed.

Nitrogen Tetroxide. Hyponitric Acid.

Symbol, N_2O_4 or NO_2. Molecular weight, 46. Density, 23.

Description and Tests.—A gas; of an *orange-red* colour; liquid under pressure; has a suffocating odour; poisonous (if breathed in only small quantity producing inflammation of the lungs); solidifies at -9°C in long prisms. The chief resultant in air from decomposed nitric acid.

Preparation.—By heating the nitrate of lead ($Pb2NO_3$). Thus—

$$Pb2NO_3 + \text{heat} = PbO + O + N_2O_4.$$

Oxide of lead, oxygen, and nitrogen tetroxide are formed. (By water N_2O_4 is decomposed into nitric acid (HNO_3) and nitric oxide (N_2O_2). Thus—

$$3N_2O_4 + 2H_2O = 4HNO_3 + N_2O_2.)$$

* (3) $6Ag$ (silver) $+ 8HNO_3 = 6AgNO_3 + 4H_2O + N_2O_2$
Nitrate of silver, water, and nitric oxide are formed.

Nitrogen Pentoxide. Nitric Anhydride.

Symbol, N_2O_5. Molecular weight, 54. Density, 27.

Description and Preparation.—A white crystalline substance; in brilliant right rhombic prisms. Prepared by passing dry chlorine gas (Cl) over nitrate of silver ($AgNO_3$).* Thus—

1st Stage.—$AgNO_3 + 2Cl = AgCl + O + NO_2Cl$.
Chloride of silver, oxygen, and a yellow liquid called nitroxyl chloride are formed.

2nd Stage.—$AgNO_3 + NO_2Cl = AgCl + N_2O_5$.
Nitrate of silver and nitroxyl chloride form chloride of silver and nitrogen pentoxide. This substance (N_2O_5) very easily decomposes, and unites with great energy with H_2O. Thus—

$N_2O_5 + H_2O = H_2N_2O_6$ or $2HNO_3$; forming

Nitric Acid.

Symbol, HNO_3. Molecular weight, 63.

Description.—A fuming, corrosive, colourless liquid, with strongly acrid properties, and intensely acid taste; usually called Aqua Fortis. Entirely volatilised by heat. Specific gravity 1·517. A monobasic acid.

Sources.—Both kingdoms of nature; generally with potash, soda, lime, and magnesia, as nitrates. These are found in various parts of the world on the surface of the earth, and in some mineral waters, and are frequent constituents of vegetable juices.

Preparation.—(1) By heating sulphuric acid (H_2SO_4) with sodium nitrate ($NaNO_3$). Thus—

$NaNO_3 + H_2SO_4 = NaHSO_4 + HNO_3$.

Sodium-hydrogen-sulphate remains in the retort, and nitric acid distils over into a receiver.

(2) By heating sulphuric acid with potassium nitrate (KNO_3). Thus—

$KNO_3 + H_2SO_4 = KHSO_4 + HNO_3$.

Potassium-hydrogen-sulphate remains behind.

Tests.—For the *concentrated* acid (HNO_3)—

(1) Stains the skin *yellow*, forming *picric* or *carbazotic acid*.

(2) Nitric acid with dry morphia gives a *yellow* colour, passing into *red*; with brucia an immediate scarlet is produced.

(3) HNO_3 in the presence of hydrochloric acid dissolves *gold leaf*.

(4) Gives off ruddy brown fumes with some metals, as copper, mercury, silver, &c.

(5) Gives *white* fumes with the vapour of ammonia.

* Or—$2AgNO_3 + 2Cl = 2AgCl + O + N_2O_5$.
Chloride of silver, oxygen, and nitric anhydride are formed.

(6) Bleaches a solution of indigo.

(7) When poured on red-hot powdered charcoal, brilliant combustion is produced.

For the *diluted* acid, or a *nitrate*—

Upon the addition of a *green* crystal of ferrous sulphate, with a drop or two of strong sulphuric acid, the crystal is turned to a *red-brown* colour, ferric sulphate being formed.

Nitric acid forms salts called nitrates. They are all soluble in H_2O, and deflagrate upon charcoal.

Action of Nitric Acid on the Metals.

Gold, platinum, and aluminum are unattacked by nitric acid, HNO_3. Tin (stannum, Sn) is oxidised to meta-stannic acid ($H_2Sn_5O_{11} + 4H_2O$), antimony (stibium, Sb) to antimonic acid ($HSbO_3$), both insoluble in H_2O. Copper (Cu) is converted into soluble cupric nitrate ($Cu2NO_3$), mercury (Hg) into mercurous nitrate ($HgNO_3$) or mercuric nitrate, ($Hg2NO_3$), silver (Ag) into argentic nitrate ($AgNO_3$), zinc (Zn) into zinc nitrate ($Zn2NO_3$).

THE ATMOSPHERE

Is the gaseous envelope of the earth, and forms the ocean of air at the bottom of which we live. The average composition of air may be said to be the following :—

100 volumes of air contain—

Oxygen	20·6	volumes.
Nitrogen	77·9	,,
Carbonic anhydride	0·04	,,
Aqueous vapour (about)	1·46	,,
Ammonia	traces.	
Ozone		
Nitric acid		
Marsh gas		
Sulphurous anhydride		
Sulphuretted hydrogen (in towns)		
	100 00	

As most of the last-named ingredients are present in small and variable proportion, they are generally separated first in an analysis of air.

By oxygen, animal life is supported ; the nitrogen serves to dilute the oxygen ; carbonic anhydride and ammonia nourish plants ; water favours the absorption of these, and ozone purifies the air.

Of *carbonic acid*, there are present from 4 to 6 volumes in

10·000 of air. The proportion of ozone is various, but is greater in the country than in town. To detect the carbonic acid, we expose a vessel containing lime-water to the open air. The lime-water soon becomes turbid, from the formation of insoluble carbonate of lime.

The amount of aqueous vapour is dependent for the most part upon temperature, and varies with latitude, season, and region, &c.

The quantity of ammonia in the form of carbonate and nitrate is small, being about 1 part in 1,000,000 of air: its presence can only be shown by acting upon large quantities of air.

Oxygen may be proved to exist in the air, by combustible bodies being converted into oxides when made to burn in it, Thus, by burning hydrogen (H) we have water (H_2O) formed.

The existence of nitrogen is demonstrated by the result of combustion in confined portions of air, as has been shown previously in the section on preparing this gas.

The pressure of the atmosphere is observed when we remove the air from beneath the hand by an air pump; we then find that the hand is pressed down with a force equal to 15lbs. on every square inch. From this it is evident that the human body must consequently support *several tons*, but under ordinary circumstances this pressure is not perceptible, since it is exerted *equally* in every direction.

To measure the pressure of the air we make use of

The Barometer.

This consists in the simplest form of a *straight glass tube*, about 800 millimetres (33 inches) in length, open at one end, and closed at the other. It is filled with mercury, and placed open end downwards in a vessel containing the same metal. The mercury then sinks in the tube to a point about 760 millimetres (32 inches) from the surface of the mercury in the vessel. In this position it is sustained by the force exerted by the air. As this pressure increases, the height of the mercurial column becomes greater; as it diminishes, so does the column fall. In order to compare the bulk of two gases, they must always be compared under like conditions of pressure and temperature; it is, therefore, agreed to compare all the volumes of gases at the *standard pressure of* 760 *millimetres of mercury, and at the standard temperature of* 0°C. It is difficult to say where the air exactly ceases, but it seems that the limit is about 45 miles from the level of the sea. Of course, the atmosphere having weight and elasticity,

its lower layers must be more compressed than those above them; but if the whole atmosphere were throughout of the same density, it would only reach to a height a little more than 5 miles above the sea level.

As to the *chemical constitution of the atmosphere*, it must be borne in mind that the air is *not a chemical compound*, but a *mechanical mixture* of its constituents. This conclusion is arrived at on the following grounds:

(1) If O and N are brought together in the proportions in which they are found in air, *no elevation of temperature, and no alteration in bulk* takes place (as is the case when gases combine chemically), and still the mixture acts exactly like air.

(2) The relative quantities of the two gases are *not those of their combining weights, nor of any simple multiples of these weights.*

(3) Although in general the proportions of the two gases are constant, instances not unfrequently occur in which *this ratio differs* from the ordinary one.

(4) When air is shaken up with water, some of it is dissolved, but can be easily expelled by boiling; upon analysis the expelled air is found to consist of oxygen and nitrogen in the relative proportions of 1 to 1·87. It would have been quite impossible to decompose the air by simply shaking it up with water if it had been a chemical compound; *the compound would have dissolved as a whole*, and, upon analysis, the air expelled by boiling would have consisted of oxygen and nitrogen as 1 to 4, the proportions of the original air.

The air is therefore only a mixture, since a larger amount of O is dissolved than corresponds to that contained in the atmosphere, a fact due to the greater solubility in water of oxygen over nitrogen.

The best method of determining the amounts by volume of O and N contained in the air is by the *Eudiometer* (*eudia*, clear weather; *metron*, a measure; a measure of the clearness or purity of the air, viz., what quantity of oxygen it contains). The same arrangement is used as in the eudiometric synthesis of water. Into the tube, previously filled with mercury, air is introduced in sufficient quantity to fill it about one-sixth full. We can accurately ascertain the volume of this air by reading off the number of millimetre divisions on the tube to which the mercury rises.

A quantity of pure hydrogen, more than sufficient to combine with all the oxygen present, is now added, and the volume of this gas determined. An electric spark is then passed

through the mixture, and after the explosion *the volume* is determined as before. This is found to be less than before explosion, water having been formed by the union of the whole of the oxygen with part of the hydrogen. We already know that 2 volumes of H unite with exactly 1 volume of O to form H_2O (water); then one-third of the diminution in volume represents the O that has disappeared, and therefore the volume of O contained in the air taken. Now suppose the quantity of air amounted to 100 volumes, and after the addition of the hydrogen the volume of the mixture was 150 volumes. After explosion we find 87 volumes remain, therefore 63 volumes have disappeared. Then the volume of O contained in 100 volumes of air is

$$\frac{63}{3} = 21.$$

The most careful analyses of air collected in various parts of the globe have shown that the relative quantities of O and N remain the same, or nearly the same, from whatever region obtained. Whether from the depths of mines, from 20,000 feet above the surface of the earth, from the Arctic seas, or from the tropics, the air contains from 20·9 to 21 volumes of oxygen per cent.

The composition of air by volume, and the relative densities of the constituent gases (N = 14; O = 16) being known, its composition by weight can be calculated. Thus, in 100 grams of air, we find that 76·84 grams of N are mixed with 23·16 grams of O, and the mean of a large number of experiments shows that 100 parts by weight of air contain 77 parts by weight of N and 23 of O.

CARBON (carbo, coal).

Symbol, C. Combining weight, 12. Density, 12.

Description.—A solid element. A tetrad replacing 4 atoms of monad hydrogen, as shown in the composition of marsh gas $C\left\{\begin{matrix}H\\H\\H\\H\end{matrix}\right.$ and existing in 3 "allotropic" modifications, viz.:—

(1) The diamond.
(2) Graphite, plumbago, or, black-lead.
(3) Charcoal, lamp-black, or, amorphous carbon.

The Diamond.

The purest form of carbon, and the hardest gem known:

can be entirely converted into carbonic dioxide (CO_2) by combustion in O. By intense heat, in absence of air, it is reduced to a coke-like substance. The specific gravity varies from 3·3 to 3·5. It crystallizes in cubes and octahedra, and is insoluble in all media, and infusible. Is largely used for glass-cutting, and is cut into various forms by its own dust. The mode in which the diamond has been formed is unknown.

Graphite, or Plumbago.

A black metallic-looking substance, hence the name black-lead; leaves a greasy stain when drawn upon paper. Crystallises in 6-sided plates, bearing no relation to the form of the diamond. Sp. gr. 2·18 to 2·38. It is much used for the manufacture of pencils.

Charcoal, or Amorphous Carbon.

Is the light-giving principle of flame. The purest form of charcoal-carbon is lamp-black. It also occurs as wood-charcoal, coal, coke, and animal-charcoal. Much lighter than the other forms. Sp. gr. varies from 1·6 to 2·0. A piece of charcoal floats upon water in consequence of its porosity, but if finely powdered it instantly sinks. It is a great absorbent of gases and colouring matters, and is used as a disinfectant in hospitals, &c. *Carbo ligni, wood-charcoal,* is obtained from wood charred by exposure to a red heat, without access of air.

Carbon with Oxygen

forms two compounds, viz.:

(1) Carbon monoxide, or carbonic oxide .....CO.
(2) Carbon dioxide, or carbonic anhydride...CO_2.

Carbon Monoxide.

Symbol, CO. Molecular weight, 28. Density, 14.

Description.—A gas, not occurring naturally, but artificially produced. Colourless, with slightly oppressive odour. Very poisonous. Does not support combustion, but *burns with a light-blue flame,* forming carbonic anhydride (CO_2). Sp. gr. (air = 1) is 0·969. Very slightly soluble in H_2O. Discovered by Priestley in 1787. CO forms with chlorine a compound called *phosgene* gas.

Preparation.—(1) By passing carbonic anhydride (CO_2) over red-hot charcoal (C). Thus—

$$CO_2 + C = 2CO.$$

(2) By heating oxalic acid ($H_2C_2O_4$) with sulphuric acid (H_2SO_4). Thus—

$$H_2C_2O_4 + H_2SO_4 = H_2SO_4, H_2O + CO_2 + CO.$$

The sulphuric acid abstracts the elements of water (H_2O); the carbonic anhydride and carbon monoxide are evolved as gases, and are collected in a long cylindrical tube; upon shaking up lime water (CaH_2O_2) in the tube, carbonate of lime ($CaCO_3$) is formed, and carbon monoxide left.

(3) By heating zinc (Zn) and chalk ($CaCO_3$) to redness in a gun-barrel. Thus—

$$Zn + CaCO_3 = ZnO + CaO + CO,$$

Oxide of zinc, lime, and carbon monoxide are formed.

(4) By heating carbonic anhydride (CO_2) and hydrogen. Thus—

$$CO_2 + 2H = H_2O + CO.$$

(5) By heating ferrocyanide of potassium ($K_4FeC_6N_6$, $3H_2O$) with sulphuric acid (H_2SO_4) and water (H_2O). Thus—

$$K_4FeC_6N_6, 3H_2O + 3H_2O + 6H_2SO_4 = 2K_2SO_4 + FeSO_4 + 3(NH_4)_2SO_4 + 6CO,$$

Sulphate of potash, sulphate of iron, sulphate of ammonia, and carbon monoxide are formed.

Carbon Dioxide. Carbonic Anhydride.

Symbol, CO_2. Molecular weight, 44. Density, 22.

Description.—A gas; colourless, inodorous, with a slightly acid taste. Tolerably soluble in water; neither combustible nor supporting combustion. Liquid under pressure, and then solid by spontaneous evaporation, forming snow-white flakes. Constitutes the "choke-damp" and "after-damp" of mines; specific gravity 1·529. Discovered by Black in 1756.

Sources.—Occurs free in the air, and in the waters of many mineral springs. Is evolved from the craters of active volcanoes. Is given off in the processes of fermentation, respiration, combustion, decay, putrefaction, and germination. When a room contains 0·10 per cent. of CO_2 it is unfit for continued respiration. Combined with lime and magnesia, carbon dioxide occurs plentifully in nature.

Its salts are called carbonates, and except the alkaline carbonates are mostly insoluble.

CO_2 gives a white precipitate with lime-water.

Preparation.—(1) By heating calcium carbonate ($CaCO_3$) to redness. Thus—

$$CaCO_3 + \text{red heat} = CaO + CO_2.$$

Lime and carbon dioxide are formed.

(2) By pouring hydrochloric acid (HCl) upon chalk, marble or other form of carbonate of lime, ($CaCO_3$.) Thus—

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2,$$

Chloride of calcium, water, and carbonic anhydride are formed.

(3) Charcoal burns in oxygen to CO_2.

Carbonic anhydride (CO_2) + H_2O = Carbonic acid (H_2CO_3.)

Compounds of Carbon with Hydrogen.

These are very numerous, and exist in gaseous, liquid, and solid forms. For the present we shall only deal with three of the simplest, leaving the remainder for consideration under Organic Chemistry.

(1) Methyl Hydride, Methane, Light Carburetted Hydrogen, or Marsh Gas, CH_4.

(2) Acetylene, C_2H_2.

(3) Ethylene, Heavy Carburetted Hydrogen, or Olefiant Gas, C_2H_4.

Methyl Hydride. Marsh-Gas.

Symbol, CH_4. Molecular weight, 16. Density, 8.

Description and Sources.—A gas; colourless, inodorous, and tasteless. Known as "*Firedamp*" in coal mines. Produced in *stagnant pools* by the decomposition of dead leaves (hence its name, marsh-gas). A constituent of coal gas, and evolved in volcanic districts.

Preparation.—It cannot be prepared by the direct union of its elements, but is produced in the following modes:

(1) By heating acetate of sodium ($NaC_2H_3O_2$) with caustic soda (NaHO). Thus—

$$NaC_2H_3O_2 + NaHO = Na_2CO_3 + CH_4,$$

Carbonate of soda and marsh-gas are formed.

(2) By passing a mixture of carbon disulphide vapour (CS_2) and sulphuretted hydrogen (H_2S) over red-hot copper (Cu). Thus—

$$8Cu + CS_2 + 2H_2S = 4Cu_2S + CH_4.$$

Cuprous sulphide and marsh-gas result.

This gas burns with *a blueish-yellow non-luminous flame*, forming carbon dioxide and water. When mixed with *ten times its volume of air, or twice its volume of O*, it explodes suddenly and violently upon ignition.

Acetylene.

Symbol, C_2H_2. Molecular weight, 26. Density, 13.

Is formed by the direct union of carbon and hydrogen, at a very high temperature. It is a colourless gas, burning with a bright luminous flame, and having a peculiar disagreeable odour which may be noticed when a candle burns with a smoky flame. It combines with certain metals, as copper and silver, and these compounds very easily decompose with explosion. C_2H_2 unites directly with hydrogen to form

ETHYLENE.

Symbol, C_2H_4. Molecular weight, 28. Density, 14.

Description and Sources.—A gas; colourless, with a sweetish taste; has been condensed by high pressure and a temperature of -110°C to a colourless liquid. It is an important constituent of coal-gas, and burns with a *smoky luminous* flame, forming carbon dioxide and water. Detonates powerfully when mixed *with three times its bulk* of oxygen and fired. It is called olefiant gas, because it combines directly with its own volume of chlorine gas (Cl), to form an oily liquid, $C_2H_4Cl_2$, termed Dutch liquid, or ethylenic dichloride. Discovered by some Dutch chemists in 1796.

Preparation.—(1) By the destructive distillation of coal. (2) By heating alcohol (C_2H_6O) with sulphuric acid (H_2SO_4) at a temperature above 154°C,* thus—

$$C_2H_6O + H_2SO_4 = H_2SO_4,H_2O + C_2H_4.$$

The sulphuric acid abstracts the elements of water, and C_2H_4 is evolved as a gas.

COAL GAS.

In order to prepare this gas, the coal is heated in a closed retort.

The results of this heating are—

(1) *Volatile bodies* formed and expelled.

(2) A residue of impure carbon left as *coke.*

The volatile products are tar, ammonia, water, and gas. The tar yields substances from which the *aniline colours* are produced.

The ammonia is the chief source of the *ammoniacal salts.*

The gas consists of (1) *luminous* and (2) *non-luminous substances.*

The *luminous* gases are olefiant gas (C_2H_4) and other hydrocarbons having an analogous composition, as C_3H_6, C_4H_8, C_5H_{10}, &c.

The *non-luminous* gases are hydrogen (H), carbonic oxide (CO) and marsh-gas (CH_4).

The *impurities* are carbon dioxide (CO_2), sulphuretted hydrogen (H_2S), and the vapour of carbon disulphide (CS_2).

THE STRUCTURE OF FLAME.

Flame is gas highly ignited. The hottest flames do not necessarily give off much light. Luminosity depends upon the presence of solid matter which becomes heated to whiteness. In a burning candle the flame presents three separate parts, viz.:

* Between 127°C and 154°C, ether is produced.

(1) The *dark* central zone of *unburnt* gas around the wick;
(2) The *luminous* zone of *incomplete* combustion;
(3) The *non-luminous* zone of *complete* combustion.

The blow-pipe flame can be divided into two parts:-

(1) The *oxidizing* or *outer* flame, with excess of oxygen, and
(2) The *reducing* or *inner* flame, with excess of carbon.

THE DAVY LAMP.

A certain temperature is required to inflame every mixture of gases; until this temperature is attained, the mixture will not take fire. A flame may be cooled sufficiently to put it out by placing a coil of cold copper wire over it, but if the coil be previously heated, the flame continues to burn. If a piece of wire gauze containing about 700 meshes to the square inch be held close over a jet of gas, and the gas lighted above, we may remove the gauze several inches above the jet, and the inflammable gas does not take fire *below*, the flame burning only *above* the gauze. The heat is so quickly conducted away by the wires, that the temperature of the gas at the lower side of the gauze is not raised sufficiently high to produce ignition. Upon this principle Sir Humphry Davy constructed his safety lamp. Thus—

An oil lamp is enclosed in a wire gauze covering; air can pass through the meshes of the gauze, and the products of combustion of the oil can escape, but still no flame can proceed from the inside to the outside of the gauze; if the lamp be placed in a most inflammable mixture of air and firedamp, immediate ignition *externally* is not possible, although the mixture takes fire and burns *inside* the gauze. Of course, after a time, when the gauze becomes over-heated, the surrounding firedamp may attain the temperature requisite for its ignition.

Carbon with Nitrogen forms

Cyanogen (kuanos, blue, genesis, a generator).

Symbol, CN (sometimes Cy). Molecular weight, 26.

Description.—A gas; colourless and poisonous, with an odour of peach blossoms. Specific gravity 1·806. Does not support combustion, but *burns with a rose-coloured flame*, forming carbon dioxide and free nitrogen. Combines with metals to form cyanides. Belongs to a class of bodies called *compound radicals*, and is monobasic, replacing one atom of monad hydrogen, as shown in the composition of prussic acid, H/CN. Has been condensed to a colourless liquid.

Preparation.—By heating a metallic cyanide, such as mercuric cyanide (HgC_2N_2 or $HgCy_2$); metallic mercury and a black substance (paracyanogen) are left, and cyanogen gas is given off. It is best collected over mercury, since water dissolves 4 times its bulk of the gas.

Carbon and nitrogen do not unite together, but by passing N over a white-hot mixture of charcoal (C) and carbonate of potash (K_2CO_3) we obtain cyanide of potassium (KCN). Thus—

$$K_2CO_3 + 2N + 4C = 3CO + 2KCN.$$

From this KCN can be prepared a number of bodies, all containing CN, and possessing peculiar properties. The name cyanogen is given to this group on account of its forming with iron some blue compounds.

A compound of cyanogen with iron and potassium called *Ferrocyanide of Potassium* (K_4FeCy_6, $3H_2O$) or *Yellow* Prussiate of Potash is prepared by heating together horns and hoofs and clippings of hides in an iron pot with carbonate of potash. By passing chlorine gas through K_4FeCy_6, $3H_2O$, we obtain *Ferricyanide of Potassium* (K_3FeCy_6) or *Red* Prussiate of Potash. Thus—

$$K_4FeCy_6, 3H_2O + Cl = KCl + 3H_2O + K_3FeCy_6.$$

Chloride of potassium, water, and ferricyanide of potassium result.

This latter salt gives no special precipitate with *persalts* of iron, but yields a *dark blue precipitate* with the *protosalts* of that metal.

Cyanogen with Hydrogen
forms
Hydrocyanic or Prussic Acid.

Symbol, HCN or HCy. Molecular weight, 27.

Description.—In the anhydrous or undiluted state this substance is a colourless, limpid, volatile liquid. Specific gravity, 0·7058 at 5°C, boiling at 26°C. Feebly acid, with odour of peach blossoms or bitter-almond oil. Dreadfully poisonous, inhalation even in small quantities producing giddiness and headache. It occurs in small quantities in some kernels and leaves of the orders Amygdaleæ and Pomeæ. Discovered by Scheele in 1782.

Preparation.—(*a*) In a *hydrated* form.

(1) By acting upon cyanide of potassium (KCN) with diluted sulphuric acid (H_2SO_4, H_2O). Thus—

$$2KCN + H_2SO_4 + H_2O = K_2SO_4 + H_2O + 2HCN,$$

Sulphate of potash, water, and prussic acid are formed.

(2) By boiling sulphuric acid (H_2SO_4) with ferrocyanide of potassium (K_4FeCy_6, $3H_2O$). Thus—

$$2K_4FeCy_6, 3H_2O + 3H_2SO_4 = K_2Fe_2Cy_6 + 3K_2SO_4 + 6H_2O + 6HCy,$$

Everitt's yellow salt, sulphate of potash, water and prussic acid are formed.

(*b*) In an *anhydrous* form.

(3) By passing sulphuretted hydrogen gas (H_2S) over dry mercuric cyanide (HgC_2N_2). Thus—

$$HgC_2N_2 + H_2S = HgS + 2HCN,$$

Mercuric sulphide and prussic acid result.

Tests.—

(1) Its odour and volatility.

(2) The formation of the *white cyanide of silver* upon the addition of a solution of nitrate of silver ($AgNO_3$). Thus—

$$AgNO_3 + HCy = HNO_3 + AgCy,$$

Nitric acid and cyanide of silver are formed.

The cyanide of silver has the following characters:

(*a*) It is soluble in *boiling strong nitric acid.*

(*b*) When heated it gives off *cyanogen gas* which, upon the application of a light, burns with a *rose-coloured* flame.

(3) The formation of *Prussian blue* $\left\{ Fe_4(FeCy_6)_3 + 18H_2O \right\}$ by the following method:

Liquor Potassæ (KHO) is added to the prussic acid (HCy) forming cyanide of potassium (KCy); then a proto- and per-salt of iron are added; this operation is followed by the formation of a proto- and per- cyanide of iron; but Prussian blue *cannot exist* in the presence of the alkali *potash*, so a mineral acid (sulphuric acid is the best) is employed to neutralize the alkali. Upon the addition of this acid, the Prussian blue is immediately developed. Thus—

$$\left\{ \begin{matrix} \text{Prussic acid} \\ 18HCy \end{matrix} \right. + \left\{ \begin{matrix} \text{Liq. potassæ} \\ 18KHO \end{matrix} \right. + \left\{ \begin{matrix} \text{Ferrous sulphate} \\ 5FeSO_4. \end{matrix} \right.$$

$$+ \left\{ \begin{matrix} \text{Ferric Sulphate} \\ Fe_2(SO_4)_3 \end{matrix} \right. + \left\{ \begin{matrix} \text{Sulphuric acid} \\ H_2SO_4 \end{matrix} \right. = \left\{ \begin{matrix} \text{Sulphate of potash} \\ 9K_2SO_4 \end{matrix} \right.$$

$$+ \left\{ \begin{matrix} \text{Hydrogen} \\ 2H \end{matrix} \right. + \left\{ \begin{matrix} \text{Ferrocyanide of Ferric iron or Prussian blue} \\ Fe_4(FeCy_6)_3, 18H_2O. \end{matrix} \right.$$

(4) The formation of the *blood-red sulpho-cyanide of iron* ($Fe_2(SCy)_6$) as follows:

Some prussic acid is heated upon a watch-glass to a syrupy consistence with a drop or two of sulphide of ammonium (NH_4HS). Thus—

(*a*) $HCy + NH_4HS = 2H + NH_4SCy$:

Hydrogen and sulphocyanide of ammonium (white) result.

(*b*) Perchloride of iron (Fe_2Cl_6) is added to NH_4SCy. Thus—

$$6NH_4SCy + Fe_2Cl_6 = 6NH_4Cl + Fe_2(SCy)_6.$$

Chloride of ammonium and sulphocyanide of iron (red) are formed.

The *Acidum Hydrocyanicum Dilutum* of the British Pharmacopœia consists of hydrocyanic acid dissolved in water and constitutes 2 per cent. by weight of the solution.

Scheele's prussic acid contains 4 per cent. of the anhydrous acid.

The anhydrous acid is very volatile, and speedily decomposes into a carbonaceous mass. The diluted acid can be much longer preserved if a trace of a mineral acid be present.

The strength of any solution of prussic acid may be detected by adding a solution of nitrate of silver to 100 grains of the solution as long as a precipitate falls. Collect this, dry and weigh it, and divide its weight by 5; the answer will be the per-centage. Thus, if 10 grains fall, then there is 2 per cent. present.

THE HALOGENS.

Under this heading we describe four elements, viz.:—*Chlorine, Bromine, Iodine, and Fluorine.* They have received this name from the fact of their forming salts *analogous in their composition* to common salt, or chloride of sodium (NaCl).

CHLORINE (chloros, green).

Symbol, Cl. Atomic weight, 35·5. Density, 35·5.

Description and Sources.—A gas; never native; of a *greenish yellow colour* with a peculiar *disagreeable odour*, which in small quantities resembles that of seaweed; in large quantities a powerful irritant, causing inflammation of the mucous membrane, and even producing a fatal result when inhaled. Can be condensed to a heavy yellow liquid, but has never been solidified. Found combined with metals as chlorides. *Dry* chlorine will *not bleach*, but *when water is added does so powerfully.* Only bleaches *vegetable colours*, mineral colours being unaffected. Is not combustible, but supports combustion. An aqueous solution of chlorine will dissolve gold leaf. Discovered by Scheele in 1774. Liquefied by a pressure of 4 atmospheres.

Preparation.—(1) By heating the dioxide of manganese (MnO_2) with hydrochloric acid (HCl). Thus—

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + 2Cl,$$

Manganese chloride, water, and chlorine result.

(2) By heating sulphuric acid (H_2SO_4) with dioxide of manganese (MnO_2) and chloride of sodium (NaCl). Thus—

$$2NaCl + MnO_2 + 2H_2SO_4 = Na_2SO_4 + MnSO_4 + 2H_2O + 2Cl.$$

Sulphate of soda, sulphate of manganese, water and chlorine are formed.

This gas cannot be collected over cold water or mercury, since the former dissolves 2·37 volumes of Cl at 15°C, and with the latter mercuric chloride is formed. It may be collected by displacement, being nearly 2·5 times as heavy as air, but is conveniently prepared over *warm* water.

Tests.—(1) Its *greenish-yellow* colour, and its odour.

(2) A lighted candle placed in Cl *continues to burn*, but with a very *smoky* flame; the hydrogen of the wax enters into combination with the Cl forming hydrochloric acid (HCl), whilst its carbon is given off from the wax as soot.

(3) Phosphorus burns *spontaneously* in chlorine.

(4) Certain metals, as arsenic, antimony, copper and gold, *in a fine state of division or attenuation*, and paper dipped in oil of turpentine, take fire *spontaneously* when thrown into chlorine.

Chlorine with Hydrogen forms Hydrochloric Acid. Hydric Chloride.

Symbol, HCl. Combining weight, 36·5. Density, 18·25.

Description.—A gas; colourless, poisonous, and pungent, neither combustible nor supporting combustion. Has very acid properties and is very soluble in water, one volume of which at 15°C dissolves 454 volumes of the gas. Discovered by Priestley in 1772. Liquefied by a pressure of 40 atmospheres.

Preparation.—(1) By the union of H and Cl, in equal volumes, in the sunlight or by heat. Thus—

$$H + Cl = HCl.$$

(2) By heating sulphuric acid (H_2SO_4) upon chloride of sodium (NaCl). Thus—

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl.$$

Sodium sulphate and hydrochloric acid are formed.

Tests.—For the strong or *concentrated* acid (a solution of the gas in water).

(1) *Whitens* the skin, forming chloride of albumen.

(2) *Dissolves gold leaf* in the presence of nitric acid (HNO_3).

(3) Gives off *chlorine gas* when added to dioxide of manganese.

(4) Gives *white fumes* with the vapour of ammonia.

For the *diluted* acid or a *soluble chloride.*

Nitrate of silver ($AgNO_3$) gives a *white* precipitate of the chloride of silver ($AgCl$). This precipitate is recognised by the following characters—

(*a*) It is soluble in liquor ammoniæ, and reprecipitated by nitric acid.

(*b*) It blackens by exposure to light.

(*c*) When heated, it melts to a mass called horn silver.

Hydrochloric acid, when added to nitric acid, forms—

Aqua Regia.—This mixture dissolves the noble metals, namely gold and platinum, the solvent action being dependent upon the chlorine, which is set free by the oxidising agency of the nitric acid upon the hydrogen of the HCl, soluble chlorides being formed. The nitric acid is reduced to nitrogen dioxide (N_2O_2); and nitrous oxychloride ($NOCl$), and nitric oxychloride ($NOCl_2$), are liberated as yellowish gases.

Compounds of Chlorine with Oxygen.

Chlorine and oxygen do not unite directly, but indirectly they form the following compounds, viz. :—

Cl_2O, chlorine monoxide, yielding $HClO$ hypochlorous acid. Thus—

$$Cl_2O + H_2O = 2HClO.$$

Cl_2O_3, chlorine trioxide, yielding $HClO_2$, chlorous acid. Thus—

$$Cl_2O_3 + H_2O = 2HClO_2.$$

Cl_2O_4, chlorine tetroxide.

$HClO_3$, chloric acid.

$HClO_4$, perchloric acid.

No acid corresponding to chlorine tetroxide, or any oxides corresponding to chloric and perchloric acids, have as yet been prepared.

Chlorine Monoxide.

Symbol, Cl_2O. Molecular weight, 87. Density, 43·5.

Description.—A gas, condensible to a red explosive liquid, very soluble in water, forming a yellow solution which bleaches vegetable colours more entirely than chlorine.

Preparation.—From mercuric oxide (HgO) and chlorine (Cl). Thus—

$$2HgO + 4Cl = Hg_2Cl_2O + Cl_2O.$$

Mercuric oxychloride, and chlorine monoxide, are formed.

Bleaching Powder

Is a mixture of chloride of calcium ($CaCl_2$), and hypochlorite

of calcium ($CaCl_2O_2$). It is prepared by passing chlorine gas (Cl) into slaked lime (CaH_2O_2). Thus—

$$2CaH_2O_2 + 4Cl = 2H_2O + CaCl_2 + CaCl_2O_2.$$

The chlorine for this preparation is now obtained on a large scale by passing hydrochloric acid gas and air over heated sulphate of copper ($CuSO_4$). The H of the HCl, and the O of the air form water, setting free the chlorine. The sulphate of copper undergoes no change whatever.

Hypochlorous Acid.

Symbol, HClO.

A colourless liquid with a peculiar smell and strong bleaching properties.

Preparation.—From carbonate of lime ($CaCO_3$), water (H_2O), and chlorine (Cl). Thus—

$$CaCO_3 + H_2O + 4Cl = CO_2 + CaCl_2 + 2HClO.$$

Carbonic anhydride, chloride of calcium, and hypochlorous acid are formed.

Chlorine Trioxide.

Symbol, Cl_2O_3.

A gas of a deep yellowish-green colour. Formed by the action of nitric acid (HNO_3) upon arsenious anhydride (As_2O_3), chlorate of potash ($KClO_3$) and water (H_2O). Thus—

$$2KClO_3 + As_2O_3 + 2HNO_3 + 2H_2O = 2H_3AsO_4 + 2KNO_3 + Cl_2O_3.$$

Arsenic acid, nitrate of potash, and chlorine trioxide result.

Chlorous Acid.

Symbol, $HClO_2$.

Is prepared by condensing Cl_2O_3 gas in water; it is a greenish-yellow liquid, which bleaches and oxidises.

Chlorine Tetroxide.

Symbol, Cl_2O_4.

A deep yellow gas, and at -20°C a red liquid.

Preparation.—By the action of sulphuric acid (H_2SO_4) upon chlorate of potash ($KClO_3$). Thus—

$$6KClO_3 + 3H_2SO_4 = 3K_2SO_4 + 2HClO_4 + 2H_2O + 2Cl_2O_4.$$

Sulphate of potash, perchloric acid, water, and chlorine tetroxide result, the gas being collected by displacement.

This gas is very liable to decompose with violent explosions, and is soluble in water, yielding mixtures of chlorite and chlorate.

Chloric Acid.

Symbol, $HClO_3$.

A syrupy, strongly acid liquid, and a powerful oxidising

agent. When dropped upon paper it takes fire, giving up its oxygen; forms salts called chlorates, all of which are soluble in water.

Preparation.—From barium chlorate ($Ba2ClO_3$) and sulphuric acid (H_2SO_4). Thus—

$$Ba2ClO_3 + H_2SO_4 = BaSO_4 + 2HClO_3.$$

Sulphate of baryta and chloric acid result.

Perchloric Acid.

Symbol, $HClO_4$. Molecular weight, 100·5.

Description.—An oil-like liquid, forming with water a crystalline hydrate. One of the most powerful oxidising agents known; if dropped on wood or paper it instantly causes ignition, and when thrown on charcoal it decomposes with detonation. It is the most stable of all the acids derived from chlorine.

Preparation.—By distilling chlorate of potash ($KClO_3$) with sulphuric acid (H_2SO_4) in a retort. Thus—

$$4KClO_3 + 2H_2SO_4 = 2K_2SO_4 + H_2O + 3O + 2Cl + 2HClO_4.$$

Sulphate of potash, water, oxygen, chlorine and perchloric acid are formed.

The following, then, is the unbroken series of the acids of chlorine, increasing step by step by one atom of O:—

HCl, hydrochloric acid.
$HClO$, hypochlorous acid.
$HClO_2$, chlorous acid.
$HClO_3$, chloric acid.
$HClO_4$, perchloric acid.

Compound of Chlorine with Nitrogen.

This is formed only indirectly, and its composition has not as yet been precisely ascertained. It is obtained by passing *excess* of chlorine gas through a solution of ammonia. It is an oily liquid of specific gravity, 1·653, which when touched explodes with fearful violence. Its hypothetical formula is NCl_3.

Compounds of Chlorine with Carbon.

These can only be made indirectly, and amongst them are the following:

Carbon tetrachloride, CCl_4.
Ethylene chloride, C_2Cl_4.
Carbon perchloride, C_2Cl_6.
Carbon oxy-chloride, $COCl_2$.

With marsh gas (CH_4) the following stages in the substitution of hydrogen by chlorine occur :—

(1) $CH_4 + 2Cl = CH_3Cl + HCl$.
(2) $CH_3Cl + 2Cl = CH_2Cl_2 + HCl$.
(3) $CH_2Cl_2 + 2Cl = CHCl_3 + HCl$.
(4) $CHCl_3 + 2Cl = CCl_4 + HCl$.

The properties of these compounds must be left for discussion under organic chemistry.

BROMINE—(bromos, a stench).

Symbol, Br. Combining weight, 80. Density, 80.

Description.—A fluid; the only element liquid at ordinary temperatures except mercury. Of a dark reddish-brown colour by reflected light, but hyacinth-red by light transmitted through thin layers, and emitting an irritating, poisonous vapour. A monad replacing one atom of hydrogen, as seen in the composition of hydrobromic acid, H/Br.; specific gravity at 4°C is 2·966. Freezes at -22°C to a black solid, and boils at 63°C. About 30 parts of water dissolve one part of Br at 15°C. The solution has bleaching powers, but these are feebler than those of chlorine. Bromine is very soluble in alcohol, and more so in ether. Forms salts called bromides. Discovered by Balard in 1826.

Sources. — Not free in nature. Found combined with sodium and magnesium in some mineral springs, and in sea water.

Preparation.—From "bittern," the residue of sea water, after the crystallisation of common salt (NaCl). Here it exists in the form of bromide of magnesium ($MgBr_2$), and through this chlorine gas is passed. Thus—

$$MgBr_2 + 2Cl = MgCl_2 + 2Br.$$

The freed bromine is shaken up with ether, which rises with it to the surface, and is then separated by a pipette. Caustic potash (KHO) is now added, and the solution evaporated to dryness. Thus, bromide of potassium (KBr) is obtained, and to this black oxide of manganese (MnO_2), and sulphuric acid (H_2SO_4) are added. Thus—

$$2KBr + MnO_2 + 2H_2SO_4 = K_2SO_4 + MnSO_4 + 2H_2O + 2Br.$$

Sulphate of potash, sulphate of manganese, and water result, the bromine being collected and condensed in cold water.

HYDROBROMIC ACID.

Symbol, HBr. Molecular weight, 81. Density, 40·5.

Description.—A gas, colourless, strongly acid, fuming in moist air; very soluble in water.

Preparation.—H and Br will not unite directly, even in the sunlight, but can be made to do so:

(1) By passing them through a red-hot porcelain tube.

(2) By the action of Br and phosphorus (P) upon water. Thus—

$$P + 5Br + 4H_2O = H_3PO_4 + 5HBr.$$

Violent action takes place, and phosphoric acid and hydrobromic acid result.

COMPOUNDS OF BROMINE WITH OXYGEN.

(1) HYPOBROMOUS ACID ($HBrO$) is known only in aqueous solution, and the corresponding monoxide (Br_2O) is altogether unknown. This acid bleaches vegetable colouring matters; and bromine forms with slaked lime an analogue to bleaching powder, which consists of calcium bromide, and calcium hypobromite ($CaBr_2$, $CaBr_2O_2$).

Preparation.—By the action of bromine water upon red oxide of mercury (HgO). Thus—

$$HgO + 4Br + H_2O = HgBr_2 + 2HBrO.$$

Bromide of mercury and hypobromous acid are formed.

(2) BROMIC ACID ($HBrO_3$) corresponds to chloric acid ($HClO_3$) and forms bromates with metallic oxides, which are decomposed by heat in a similar manner to chlorates.

Preparation.—By the action of chlorine (Cl) upon bromine water ($Br + H_2O$). Thus—

$$Br + 3H_2O + 5Cl = 5HCl + HBrO_3.$$

Hydrochloric acid and bromic acid are formed.

(3) BROMINE PENTOXIDE (Br_2O_5) has not as yet been isolated, but

(4) PERBROMIC ACID ($HBrO_4$) has been prepared by the action of bromine upon perchloric acid ($HClO_4$). Thus—

$$Br + HClO_4 = Cl + HBrO_4.$$

Chlorine and perbromic acid resulting.

BROMIDE OF NITROGEN (NBr_3) is an oily detonating fluid.

Tests for Bromine.—(1) The *orange* bromide of starch, formed by the addition of starch to this substance.

(2) Nitrate of silver gives a light *yellow* precipitate of *bromide of silver*, sparingly soluble in liquor ammoniæ.

IODINE—(ion, a violet, eidos, like).

Symbol, I. Combining weight, 127. Density, 127.

Description.—A solid element occurring in black scales or laminar crystals, with a grey metallic lustre. Fuses at 107°C; boils at 180°C. Specific gravity, 4·95. Only slightly soluble in water, but very soluble in alcohol and ether. Upon heating gives off *violet vapours*, whence its name (*ion*, a violet, and

eidos, like). Forms salts called *iodides;* a monad element, replacing one atom of hydrogen, as shown in the composition of hydriodic acid, H/I. Its properties are not so active as those of chlorine and bromine, by which substances it is liberated from its compounds. Discovered by Courtois in 1812.

Sources.—Found combined with metals in sea-water and in various springs.

Preparation.—From a solution of "kelp," the vitrified ashes of sea-wrack. After the removal of various salts (the iodine existing as iodide of sodium, (NaI), black oxide of manganese (MnO_2) and sulphuric acid (H_2SO_4) are added. Thus—

$$2NaI + MnO_2 + 2H_2SO_4 = Na_2SO_4 + MnSO_4 + 2H_2O + 2I.$$

Sulphate of soda, sulphate of manganese, water, and iodine are formed.

Tests.—(1) The *violet vapours* produced by heating free iodine.

(2) The *blue* colour which its solution forms with starch (the iodide of starch).

With regard to the preparation of the foregoing three substances, Cl, I, and Br, it will be seen that one equation will serve for them all, making, of course, the requisite substitutions. Thus—

$$2\left\{\begin{matrix}NaCl\\NaI\\KBr\end{matrix}\right. + MnO_2 + 2H_2SO_4 = \left\{\begin{matrix}Na_2SO_4\\K_2SO_4\end{matrix}\right. + MnSO_4 + 2H_2O + 2\left\{\begin{matrix}Cl.\\I.\\Br.\end{matrix}\right.$$

Iodine with Hydrogen forms Hydriodic Acid.

Symbol, HI. Molecular weight, 128. Density, 64.

Description.—A gas; colourless, irritating and fuming, with a strong acid reaction; very soluble in water; gradually decomposed by air. Solidifies at -55°C.

Preparation.—(1) By heating iodine and hydrogen together.

(2) From tri-iodide of phosphorus (PI_3) and water (H_2O). Thus—

$$PI_3 + 3H_2O = H_3PO_3 + 3HI.$$

Phosphorous acid and hydriodic acid are formed.

IODINE WITH OXYGEN AND HYDROGEN forms the following acids :—

(1) IODIC ACID, HIO_3. Molecular weight, 176. Occurs in white crystals, and corresponds to chloric acid.

Preparation.—(1) By the oxidation of iodine by nitric acid.

(2) By the action of chlorine upon iodine water. Thus—

$$I + 3H_2O + 5Cl = 5HCl + HIO_3.$$

Hydrochloric acid and iodic acid result.

By heating HIO_3 to 170°C, we obtain iodine pentoxide (I_2O_5), a white crystalline solid.

(2) PERIODIC ACID, HIO_4. Molecular weight, 192. A white crystalline solid, which, by heat, breaks up into I_2O_5, water and oxygen.

Preparation.—From perchloric acid ($HClO_4$) and iodine. Thus—

$$HClO_4 + I = Cl + HIO_4.$$

Chlorine and periodic acid are produced.

By heating HIO_4 to 160°C we obtain *iodine heptoxide* (I_2O_7).

IODINE WITH NITROGEN

Forms a black powder (NI_3), iodide of nitrogen. This, when touched in the dry state, decomposes with a sudden loud report, or may even sometimes explode spontaneously.

Preparation.—By the action of a strong alcoholic solution of iodine upon ammonia. This may be expressed as follows :—

$$6I + 4NH_3 = 3NH_4I + NI_3.$$

Iodide of ammonium and iodide of nitrogen are formed.

FLUORINE—(fluo, to flow).

Symbol, F. Combining weight, 19.

Description.—A gas ?; colourless; not acting upon glass like hydrofluoric acid. A monad element replacing one atom of hydrogen, as shown in the composition of hydrofluoric acid, H/F. Is absorbed by caustic potash (KHO). Thus—

$$2KHO + 2F = H_2O_2 + 2KF.$$

Forming hydrogen dioxide and fluoride of potassium.

Fluorine forms no compounds with oxygen.

Sources.—Found combined with calcium as fluorspar (Derbyshire spar), or fluoride of calcium. Also in cryolite ($3NaF + AlF_3$), a double fluoride of sodium and aluminium. It has been detected in the teeth and blood of animals.

Preparation.—Has been obtained with great difficulty by passing dry iodine (I) over dry fluoride of silver (AgF). Thus—

$$AgF + I = AgI + F.$$

Iodide of silver and fluorine being formed.

Fluorine with Hydrogen forms Hydrofluoric Acid.

Symbol, HF. Molecular weight, 20. Density, 10.

Description.—A gas; colourless; very corrosive; produces painful wounds when handled; fumes strongly in the air. In contact with water it dissolves with a hissing noise, forming the hydrate ($HF, 2H_2O$).

Preparation.—From fluoride of calcium (CaF_2) by the action of sulphuric acid (H_2SO_4). Thus—

$$CaF_2 + H_2SO_4 = CaSO_4 + 2HF.$$

Sulphate of lime and hydrofluoric acid are formed.* This acid has the peculiar property of *etching* glass, by uniting with the silicon of its silica (SiO_2). Thus—

$$SiO_2 + 4HF = 2H_2O + SiF_4.$$

Water and fluoride of silicon are formed.

The Analogies, Gradations, and Relations of the Halogen Group.

(1) Chlorine is a *gas;* bromine, a *liquid;* and iodine, a *solid* at ordinary temperatures.

(2) Liquid chlorine is *transparent.* Liquid bromine *slightly so,* and liquid iodine is *opaque.*

(3) The vapour of chlorine is *yellowish-green,* that of bromine is *orange,* and that of iodine is *violet.*

(4) The sp. gr. of liquid chlorine is 1·33; of liquid bromine 2·97; and of liquid iodine, 4·95.

(5) The combining weight and, therefore, the density of bromine (80) is nearly the mean of chlorine (35·5) and iodine (127). Thus—

$$\frac{35{\cdot}5 + 127}{2} = 81{\cdot}25$$

(6) They all form, with hydrogen, compounds containing equal volumes of the constituent gases united without condensation. Thus—

H/Cl; H/Br; H/I; H/F.

(7) All these last are colourless gases which fume in air; HCl (hydrochloric acid) is *very stable;* HBr (hydrobromic acid) *not* very stable; HI (hydriodic acid) *very unstable;* HF (hydrofluoric acid) is stable.

(8) Chlorine is *readily* soluble in water, bromine only *moderately* so, and iodine is *scarcely* soluble.

(9) Chlorine displaces bromine and iodine from their com-

* Prepared in leaden or platinum vessels.

pounds; bromine displaces iodine and fluorine; and iodine displaces fluorine.

(10) All their *crystalline forms* with metals are *cubes*.

SULPHUR.

Symbol, S. Combining weight, 32. Density, 32.

Description and Sources.—A solid element, occurring native in volcanic districts, as Sicily and Iceland, crystallising in yellow rhombic octahedra; in combination, as orpiment, or arsenic trisulphide (As_2S_3), greenockite, or sulphide of cadmium (CdS); Realgar (As_2S_2); iron pyrites (FeS_2); magnetic pyrites (Fe_7S_8); silver-glance (Ag_2S); cinnabar, or sulphide of mercury (HgS); cobalt-glance, containing cobalt, arsenic and sulphur ($CoAsS$); nickel-glance, containing nickel, arsenic and sulphur ($NiAsS$); sulphide of lead, or galena (PbS); zinc sulphide, or blende (ZnS); copper sulphide (CuS). In combination with metals and oxygen as gypsum, or calcium sulphate ($CaSO_4 + 2H_2O$); heavy spar, or barium sulphate ($BaSO_4$); Glauber's salts, or sodium sulphate ($NaSO_4 + 10H_2O$); as sulphuretted hydrogen (H_2S), in certain springs, as those of Harrogate. Sulphur crystallises in two irreconcileable geometrical forms, and is hence called di-morphous. A dyad element.

Preparation.—To obtain sulphur pure, the mineral in which it is contained is heated in earthenware pots. The sulphur distils over as vapour, and is condensed in similar pots outside the furnace.

Flowers of Sulphur, is the name given to the fine crystalline powder, into which the vapour of sulphur solidifies, when it is quickly cooled below its melting point. This occurs in the same manner that aqueous vapour is deposited as snow.

Brimstone, or Roll Sulphur, is formed when sulphur is gently heated, after which it melts, and is cast into sticks.

Sulphur exists in three modifications, which are insoluble in water, and in most organic fluids, viz.:

(1) The rhombic octahedron in nature, of specific gravity 2·07; soluble in disulphide of carbon (CS_2).

(2) The long transparent needle-shaped prismatic crystals, entirely different to the first form, also soluble in CS_2. These are produced by allowing melted sulphur to cool slowly, and have the specific gravity of 1·98. The crystals become opaque after some days' exposure to air, since they split up into crystals of the natural form.

(3) A soft tenacious caoutchouc mass of specific gravity 1·96 and insoluble in CS_2, obtained by pouring melted

sulphur, heated to 230°C into cold water; at the ordinary temperature of the air, this form of sulphur assumes the ordinary brittle variety, and if heated to 100°C, it instantly changes to this form.

These modifications may be rendered apparent by simply heating sulphur: at 115°C, this substance melts, and forms an amber-coloured mobile liquid. With the rise of the temperature a dark-coloured thick treacly liquid is formed, and this at 250°C can scarcely be poured out of the vessel: above 250°C a reddish-black thin liquid is formed, which remains in this condition until the temperature of 490°C is attained, when it begins to boil, giving off a red vapour.

Sulphur is inflammable, and when heated in the air, burns with a blueish flame, forming a gas, sulphur dioxide (SO_2), which emits a suffocating odour.

Direct compounds of sulphur with chlorine, carbon, and most other elements, are known, and many metals burn in sulphur vapour, forming sulphides.

The compounds of SULPHUR WITH OXYGEN AND HYDROGEN are as follows:

(1) ... ... H_2SO_2 Hydrosulphurous acid.
(2) SO_2 Sulphur dioxide, yielding H_2SO_3 Sulphurous acid, thus:

$$SO_2 + H_2O = H_2SO_3.$$

(3) SO_3 Sulphur trioxide, yielding H_2SO_4 Sulphuric acid, thus:

$$SO_3 + H_2O = H_2SO_4.$$

(4) ... ... $H_2S_2O_3$ Hyposulphurous acid.
(5) ... ... $H_2S_2O_6$ Dithionic acid.
(6) ... ... $H_2S_3O_6$ Trithionic acid.
(7) ... ... $H_2S_4O_6$ Tetrathionic acid.
(8) ... ... $H_2S_5O_6$ Pentathionic acid.

The oxides corresponding to the acids (1) (4) (5) (6) (7) (8) are unknown. The acids sulphurous, sulphuric, and hyposulphurous, are of importance, but little is as yet known concerning the others.

HYDROSULPHUROUS ACID.

Symbol, H_2SO_2.

Description.—A yellow liquid which instantly bleaches vegetable colouring matters, and is a far more powerful reducing agent than sulphurous acid. It forms a series of salts which, although stable when dry, are, in solution, rapidly converted into hyposulphites.

Preparation.—By the action of sulphurous anhydride (SO_2) and water (H_2O) upon metallic zinc (Zn). Thus—

$$Zn + 2SO_2 + H_2O = ZnSO_3 + H_2SO_2.$$

Sulphite of zinc and hydrosulphurous acid are formed.

Sulphur Dioxide.

Symbol, SO_2. Molecular weight, 64. Density, 32.

Description.—A gas; pungent, colourless, irrespirable and suffocating; is always formed when sulphur is burnt, and is given off from volcanic craters.

Preparation.—(1) By acting upon metallic copper (Cu) with sulphuric acid (H_2SO_4) and heat. Thus—

$$Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2.$$

Sulphate of copper, water, and sulphur dioxide result.

(2) By the deoxidation of sulphuric acid (H_2SO_4) by means of wood charcoal (C) and heat. Thus—

$$2H_2SO_4 + C = 2H_2O + CO_2 + 2SO_2.$$

Water, carbonic anhydride, and sulphur dioxide, result.

This gas may be collected over mercury, or by displacement. Cold water takes up 30 times its volume of SO_2. When cooled to -10°C it condenses to a colourless liquid, and below -76°C the liquid freezes to a transparent solid.

A solution of SO_2 in water consists of true sulphurous acid or hydrogen sulphite, H_2SO_3. Upon boiling this liquid SO_2 escapes as a gas. Upon cooling a solution of the gas in water below 5°C sulphurous acid separates as a crystalline hydrate ($H_2SO_3 + 14H_2O$).

SO_2 is largely used for bleaching purposes, especially for substances not acted upon by chlorine, and also as an antichlor for getting rid of the excess of chlorine contained in the bleached rags from which paper is made. Thus—

$$SO_2 + 2H_2O + 2Cl = H_2SO_4 + 2HCl.$$

Sulphuric and hydrochloric acids are formed.

Tests.—(1) H_2SO_3 is a colourless liquid, with an odour of burning sulphur.

(2) It reduces gold chloride, precipitating metallic gold.

(3) It liberates iodine from its compounds, and, if starch be present, produces the blue iodide of amiden.

SO_2, when moistened with H_2O, bleaches in an exactly opposite manner to Cl, since SO_2 abstracts the oxygen and liberates the hydrogen, whilst Cl abstracts the hydrogen and liberates the oxygen.

Sulphur Trioxide. Sulphuric Anhydride.

Symbol, SO_3. Molecular weight, 80. Density, 40.

Sulphur dioxide gas (SO_2) and oxygen (O) will not, under ordinary circumstances, unite directly to form SO_3, but if they be passed together over finely divided and heated metallic platinum, they combine to form dense white fumes which condense to long prismatic crystals of SO_3, changing

after a time to white silky needles. This substance does not redden litmus, and when moulded by the fingers, does not char the dry skin; when in contact with water, however, combination takes place with loud hissing, like a red-hot iron, sulphuric acid, H_2SO_4, being formed. By gently heating the Nordhausen sulphuric acid (see below) SO_3 sublimes.

Sulphuric Acid. Hydrogen Sulphate.

Symbol, H_2SO_4. Molecular weight, 98.

Description.—A heavy, oily liquid, "oil of vitriol," of specific gravity 1·848, and boiling at 338°C. It chars organic bodies, and is one of the most powerful acids known.

A dibasic acid, as indicated by its composition, $\left.\begin{matrix}H\\H\end{matrix}\right\}SO_4$. Most of the acids are prepared by its agency. Discovered by Valentine in the 15th century.

Preparation.—This acid was first prepared by the distillation of ferrous sulphate ($FeSO_4+7H_2O$), and in this mode is known as *the fuming or Nordhausen acid*, having the formula $H_2SO_4 + SO_3$ (a mixture of sulphuric acid and sulphuric anhydride), a heavy, dark, fuming liquid, used only in the arts, chiefly for dissolving indigo.

The usual method of preparation is, however, *by the combustion of sulphur* (S) *and the oxidation of the resulting sulphurous anhydride* (SO_2) *by means of nitrous anhydride* (N_2O_3). The operation is conducted in huge leaden chambers, often of a capacity of 100,000 cubic feet, sulphur (S) or iron pyrites (FeS_2) being burnt at one end, and nitrate of potash (KNO_3) at the other. From the sulphur SO_2 is given off, while from the KNO_3 arises N_2O_3, which immediately parts with one atom of oxygen (O) to the SO_2, forming SO_3, or sulphuric anhydride; thus N_2O_2 is left, and this acquiring more O from the air, becomes again N_2O_3, ready to part with a fresh supply of O for the SO_2 continually coming off from the burning sulphur.

Jets of steam (H_2O) are now blown into the chamber, and uniting with the SO_3 form H_2SO_4. This acid falls to the floor of the chamber, and is continually drawn off, the excess of water being removed by evaporation. The chamber-acid is then heated as follows:

(1) In *leaden pans* until it attains a specific gravity of 1·72; then known as *the brown oil of vitriol of commerce*, and—

(2) Concentrated in *glass or platinum vessels* until the maxi-

mum specific gravity and strength are attained. We may represent the changes in the preparation as follows:

	Sulphurous anhydride		Nitrous anhydride		Nitric oxide		Sulphuric anhydride
(a)	SO_2	+	N_2O_3	=	N_2O_2	+	SO_3
	Sulphuric anhydride			Steam			Sulphuric acid
(b)	SO_3	+		H_2O		=	H_2SO_4

Tests.—For the *concentrated* sulphuric acid:

(1) Its great weight.

(2) Its energetic union with water, giving out great heat.

(3) Its charring organic bodies.

(4) With metallic copper (Cu) and heat giving off SO_2, which is known by its odour.

For the *diluted* acid or a *soluble* sulphate.

Any soluble salt of barium (Ba) as the chloride ($BaCl_2$) or the nitrate ($Ba2NO_3$) gives a white precipitate of sulphate of baryta ($BaSO_4$), insoluble in all alkalies and in all acids except boiling sulphuric, but from that deposited upon cooling. $BaSO_4$, reduced with charcoal (C) by the blow-pipe flame, yields BaS (sulphide of barium), and this gives up H_2S (sulphuretted hydrogen) upon the addition of a mineral acid.

Action of sulphuric acid upon the metals.

Upon the addition of water, zinc (Zn) and iron (Fe) are converted by H_2SO_4 into sulphate of zinc ($ZnSO_4$) and sulphate of iron ($FeSO_4$) respectively, with evolution of hydrogen (H); whilst copper (Cu) and mercury (Hg) become with heat and the same reagent sulphate of copper ($CuSO_4$) and sulphate of mercury ($HgSO_4$), with the production of sulphurous anhydride (SO_2).

Hyposulphurous Acid. Hydrogen Hyposulphite.

Symbol, $H_2S_2O_3$?; only known in metallic combination as sodium hyposulphite ($Na_2S_2O_3 + 5H_2O$), or potassium hyposulphite ($K_2S_2O_3 + 5H_2O$). It cannot be freed from the sodium or potassium. Since these salts have the power of dissolving the silver salts which have escaped the action of light, they are largely used for fixing the image in photography. Sodium hyposulphite is prepared by passing sulphur dioxide (SO_2) into a mixture of sodium sulphide (Na_2S) and caustic soda (NaHO). Thus—

$$2Na_2S + 2NaHO + 4SO_2 = H_2O + 3Na_2S_2O_3,$$

Water and sodium hyposulphite resulting.

Dithionic Acid.

Symbol, $H_2S_2O_6$; a colourless, odourless, sour liquid.

All dithionates are soluble in water.

Preparation.—(a) By acting upon manganese dioxide (MnO_2) with sulphur dioxide (SO_2). Thus—

$$MnO_2 + 2SO_2 = MnS_2O_6.$$

Manganese dithionate is formed.

(b) By the addition of barium hydrate (BaH_2O_2) to manganese dithionate (MnS_2O_6). Thus—

$$MnS_2O_6 + BaH_2O_2 = MnH_2O_2 + BaS_2O_6.$$

Manganese hydrate is precipitated, and barium dithionate left in solution.

(c) By acting upon barium dithionate (BaS_2O_6) with sulphuric acid (H_2SO_4). Thus—

$$BaS_2O_6 + H_2SO_4 = BaSO_4 + H_2S_2O_6.$$

Barium sulphate and dithionic acid are formed.

Trithionic Acid.

Symbol, $H_2S_3O_6$. This acid decomposes spontaneously into sulphur (S), sulphurous anhydride (SO_2), and sulphurous acid (H_2SO_3).

Preparation.—From potassium hyposulphite ($K_2S_2O_3$), and sulphurous anhydride (SO_2). Thus—

$$2K_2S_2O_3 + 3SO_2 = S + 2K_2S_3O_6.$$

Sulphur and potassium trithionate are formed.

The acid is freed by hydrofluosilicic acid (H_2SiF_6). Thus—

$$K_2S_3O_6 + H_2SiF_6 = K_2SiF_6 + H_2S_3O_6.$$

Potassium fluosilicate and trithionic acid being formed.

Tetrathionic Acid.

Symbol, $H_2S_4O_6$. Decomposes by heat, like trithionic acid.

Preparation.—(a) By acting upon barium hyposulphite (BaS_2O_3), with iodine (I). Thus—

$$2I + 2BaS_2O_3 = BaI_2 + BaS_4O_6.$$

Iodide of barium and tetrathionate of barium result.

(b) By acting upon BaS_4O_6, with sulphuric acid (H_2SO_4). Thus—

$$BaS_4O_6 + H_2SO_4 = BaSO_4 + H_2S_4O_6.$$

Barium sulphate and tetrathionic acid are formed.

Pentathionic Acid.

Symbol, $H_2S_5O_6$. Colourless, odourless, with an acid and bitter taste; a most unstable substance; gives a yellow precipitate with the subnitrate of mercury, and a yellow precipitate (turning black) with nitrate of silver.

Preparation.—From sulphurous acid (H_2SO_3) and sulphuretted hydrogen (H_2S). Thus—

$$5H_2SO_3 + 5H_2S = 5S + 9H_2O + H_2S_5O_6.$$

Sulphur, water, and pentathionic acid result.

SULPHUR WITH HYDROGEN forms two compounds, viz.:

(1) H_2S. Hydrogen sulphide, or sulphuretted hydrogen.
(2) H_2S_2. Hydrogen persulphide, or hydrogen disulphide.

SULPHURETTED HYDROGEN.

Symbol, H_2S. Molecular weight, 34. Density, 17.

Description.—A gas; colourless, narcotic, with an odour of rotten eggs; inflammable, burning with a blue flame, forming water and sulphurous anhydride. Discovered by Scheele in 1777.

Preparation.—(1) By passing hydrogen gas (H) through boiling sulphur (S).

(2) By the action of diluted sulphuric acid (H_2SO_4,H_2O), upon sulphide of iron (FeS). Thus—

$$FeS + H_2SO_4,H_2O = FeSO_4 + H_2O + H_2S.$$

Sulphate of iron, water, and sulphuretted hydrogen result.

(3) By the action of hydrochloric acid (HCl) upon sulphide of antimony (Sb_2S_3). Thus—

$$Sb_2S_3 + 6HCl = 2SbCl_3 + 3H_2S.$$

Chloride of antimony and sulphuretted hydrogen result.

This gas must be collected over warm water, since in cold water it dissolves to a considerable extent, imparting its peculiar odour and slightly acid reaction to the fluid. It can be condensed to a liquid, and frozen to a transparent ice-like solid. H_2S is produced by the putrefaction of such animal matters as albumen, and by the deoxidation of sulphates when decayed organic matters are present. Sulphuretted hydrogen is chiefly used as a reagent in the laboratory for the precipitation of metals, and by it these substances may be separated into two groups. Thus—

The *Copper Group.*

The following metals are precipitated by H_2S from an *acid* solution:—

Bismuthum (Bi)	Bismuth	Black or brown.
Cuprum (Cu)	Copper	
Plumbum (Pb)	Lead	
Hydrargyrum (mercurous salt) (Hg)	Mercury	
Argentum (Ag)	Silver	

Platinum (Pt)	Platinum	Black.
Aurum (Au)	Gold	
Arsenicum (As)	Arsenic	Yellow.
Cadmium (Cd)	Cadmium	
Stannum (Sn)	Tin.	
(a) Stannous salts		Brown.
(b) Stannic salts		Yellow.
Stibium (Sb)	Antimony	Orange.

The metals of this group give off sulphurous anhydride (SO_2) when heated with H_2SO_4.

The *Iron Group.*

The following are precipitated by H_2S from a neutral or *alkaline solution:*

Ferrum (Fe)	Iron.	
Ferrous and Ferric salts	. .	Black.
Manganesium (Mn) . .	Manganese,	Flesh Colour.
Cobalt (Co)	Cobalt .	Black.
Nickel (Ni)	Nickel .	Black.
Chromium (Cr) . .	Chromium.	
(a) Chromous salts .	. .	Black.
(b) Chromic salts . .	. .	Greyish-green.
Uranium (U)	Uranium.	
(a) Uranous salts . .	. .	Black.
(b) Uranic salts . .	. .	Brownish-yellow.
Zincum (Zn)	Zinc .	White.

The metals of this group give off hydrogen (H) upon the addition of H_2SO_4.

Traces of soluble sulphides in neutral or alkaline solutions give a *splendid purple colour* with nitro-prusside of sodium ($Na_4Fe_2Cy_{10}N_2O_2,4H_2O$).

HYDROGEN DISULPHIDE. HYDROGEN PERSULPHIDE.

Symbol, H_2S_2.

Description.—An oily liquid, closely resembling H_2O_2; possesses a peculiar smell, bleaches, and is readily decomposed into sulphur and sulphuretted hydrogen.

Preparation.—By the addition of calcium disulphide solution (CaS_2) to hydrochloric acid (HCl). Thus—

$$CaS_2 + 2HCl = CaCl_2 + H_2S_2.$$

Chloride of calcium and hydrogen persulphide are formed.

SULPHUR WITH CARBON forms

CARBON DISULPHIDE.

Symbol, CS_2. Molecular weight, 76. Density, 38.

Description.—A liquid; volatile, colourless, and heavy,

with an odour of cabbage water, possessing an acrid pungent taste, and very inflammable; insoluble in water, but soluble in ether and alcohol. The great solvent of gums, caoutchouc, sulphur, phosphorus, iodine, bromine, camphor, gutta-percha, and oils. Discovered by Lampadius in 1796.

Preparation.—By passing the vapour of sulphur over red-hot charcoal.

Direct compounds of sulphur with chlorine are known, viz.:

SCl, Sulphur Mono-chloride
SCl_2, Sulphur Di-chloride.

These are volatile liquids, and are formed by passing a current of chlorine gas over melted sulphur.

A remarkable analogy is observable (not only in their composition, but also in their chemical properties), between the sulphur compounds, and the corresponding bodies in the oxygen series. Thus we have—

H_2O, water.	H_2S, sulphuretted hydrogen.
H_2O_2, hydrogen dioxide.	H_2S_2, hydrogen disulphide.
CO_2, carbon dioxide.	CS_2, carbon disulphide.

PHOSPHORUS—(phos, light, pherein, to bear).

Symbol, P. Combining weight, 31. Vapour Density, 62.

The volume occupied by the atom of this substance weighing 31 is only half as large as that occupied by the atoms of each of the elements previously described. Its atomic volume is therefore ½, that of the previously described elements being 1.

Description.—Never native. Found in combination with oxygen and calcium in the bones of vertebrata, in the seeds of some plants (chiefly the cereals), and in certain minerals; a triad element. Discovered by Brandt in 1669.

Preparation.—By the following successive processes:

(1) From powdered bone-ash, which contains phosphate of lime ($Ca_3P_2O_8$) by adding sulphuric acid (H_2SO_4). Thus—

$$Ca_3P_2O_8 + 2H_2SO_4 = 2CaSO_4 + CaH_4P_2O_8.$$

Sulphate of lime, and superphosphate of lime, resulting.

(2) By the addition of charcoal (C), to the superphosphate of lime. Thus—

$$3CaH_4P_2O_8 + 10C = Ca_3P_2O_8 + 6H_2O + 10CO + 4P.$$

Phosphate of lime, water, carbonic oxide, and phosphorus are formed. The phosphorus distils over in yellow drops, and is collected under water, condensing into a solid mass.

Phosphorus exists in two allotropic forms, viz.:

(1) *A yellow wax-like solid* of specific gravity, 1·83, melting

at 44°C, and boiling at 290°C; emits a pale phosphorescent light in the dark, giving out fumes of phosphorus trioxide, P_2O_3; very inflammable and dangerous to handle. Insoluble in water, alcohol, or ether, slightly soluble in oils, and very soluble in carbon disulphide.

(2) The *red amorphous phosphorus*, of specific gravity 2·14; this does not take fire until heated above 260°C, when it passes into the ordinary form, forming phosphorus pentoxide (P_2O_5). It is *insoluble* in carbon disulphide.

Preparation of the red variety.—(1) By exposing yellow phosphorus to a temperature of 240°C for some hours in an atmosphere incapable of acting upon it chemically, such as hydrogen or carbon dioxide.

(2) By heating ordinary phosphorus in a dry tube with a trace of iodine; phosphorus iodide, and red amorphous phosphorus result.

Test.—(1) For the detection of phosphorus, the substance containing it must be dried, and a thin layer heated on a metal-plate in the dark; it then becomes luminous.

(2) After drying, add carbon disulphide; filter, and place upon a watch-glass; float it in hot water and it will become phosphorescent.

(3) Mitscherlich's test.—Place the suspected substance in a retort, acidulate it with sulphuric acid, heat and collect the products in a well-cooled receiver. A flash of light will be observed at every condensation of the phosphorus vapour.

PHOSPHORUS WITH OXYGEN forms two compounds, viz.:

(1) P_2O_3. Phosphorous anhydride, or the trioxide.
(2) P_2O_5. Phosphoric anhydride, or the pentoxide.

PHOSPHOROUS ANHYDRIDE. PHOSPHOROUS TRIOXIDE.

Symbol, P_2O_3. Molecular weight, 110.

Description.—A white non-crystalline powder; soft and readily volatile; unites with great energy with water (H_2O), forming phosphorous acid (H_3PO_3). Thus—

$$P_2O_3 + 3H_2O = 2H_3PO_3. \text{ (Hydrogen Phosphite.)}$$

Preparation.—By burning phosphorus in a *limited* current of dry air.

PHOSPHORIC ANHYDRIDE. PHOSPHOROUS PENTOXIDE.

Symbol, P_2O_5. Molecular weight, 142.

Description.—A white amorphous powder in soft snow-white deliquescent volatile flakes; absorbs water with great avidity,

hissing like a hot iron when thrown into water (H_2O), and forming orthophosphoric acid (H_3PO_4). Thus—

$$P_2O_5 + 3H_2O = 2H_3PO_4.$$ (Hydrogen Phosphate.)

Preparation.—By burning phosphorus in *excess* of air or oxygen.

PHOSPHORUS WITH HYDROGEN AND OXYGEN forms five compounds, viz.:

Hypophosphorous acid	H_3PO_2.
Phosphorous acid	H_3PO_3.
Metaphosphoric acid	HPO_3.
Phosphoric acid (tribasic)	H_3PO_4.
Pyrophosphoric acid	$H_4P_2O_7$.

HYPOPHOSPHOROUS ACID.

Symbol, H_3PO_2.

Description.—An acid syrupy fluid and powerful deoxidizer; precipitates gold and silver from their solutions. All the hypophosphites are soluble in water.

Preparation.—By acting upon barium hypophosphite $Ba(H_2PO_2)_2$ with sulphuric acid (H_2SO_4). Thus—

$$Ba(H_2PO_2)_2 + H_2SO_4 = BaSO_4 + 2H_3PO_2.$$

Sulphate of barium and hypophosphorous acid are formed.

PHOSPHOROUS ACID.

Symbol, H_3PO_3.

Description.—Deliquescent crystals which readily decompose; throws down gold, silver, and platinum from their solutions.

Preparation.—By acting upon the trichloride of phosphorus (PCl_3) with water (H_2O). Thus—

$$PCl_3 + 3H_2O = 3HCl + H_3PO_3.$$

Hydrochloric acid and phosphorous acid result.

METAPHOSPHORIC ACID.

Symbol, HPO_3.

Description.—A transparent glassy mass, known as "glacial" phosphoric acid. A monobasic acid.

Preparation.—By the addition of sulphuretted hydrogen (H_2S) to solution of metaphosphate of silver ($AgPO_3$). Thus—

$$2AgPO_3 + H_2S = Ag_2S + 2HPO_3.$$

Sulphide of silver and metaphosphoric acid are formed.

Upon the addition of cold water to this glacial acid, a solution of metaphosphoric acid is obtained, and this, upon boiling, is converted into the tribasic phosphoric acid, H_3PO_4.

Tests.—(1) Nitrate of silver gives a *white* precipitate.
(2) Albumen and acetic acid give a *white* precipitate.

Orthophosphoric Acid. Phosphoric Acid.

Symbol, H_3PO_4.

Description.—A soft liquid; a tribasic acid.

Preparation.—(1) By acting upon the tribasic phosphate of silver (Ag_3PO_4) with sulphuretted hydrogen (H_2S). Thus—

$$2Ag_3PO_4 + 3H_2S = 3Ag_2S + 2H_3PO_4.$$

Sulphide of silver and phosphoric acid are formed.

(2) By the action of nitric acid (HNO_3) upon phosphorus (P). Thus—

$$2P + 6HNO_3 = 2N_2O_3 + N_2O_4 + 2H_3PO_4.$$

Brown fumes of the tri- and tetr-oxides of nitrogen are given off, and orthophosphoric acid remains. This operation must be carefully performed.

Tests.—(1) Nitrate of silver gives a *yellow* precipitate of orthophosphate of silver.

(2) Sulphate of magnesia, and ammonia, give a *white* precipitate of triple or ammonio-magnesian-phosphate (NH_4MgPO_4).

Pyrophosphoric Acid.

Symbol, $H_4P_2O_7$.

Description.—Can be obtained as crystals by evaporation in vacuo.

Preparation.—(1) By heating the tribasic phosphoric acid (H_3PO_4) to 213°C. Thus—

$$2H_3PO_4 = H_2O + H_4P_2O_7.$$

Water and pyrophosphoric acid result.

(2) By acting upon pyrophosphate of silver ($Ag_4P_2O_7$) with sulphuretted hydrogen (H_2S). Thus—

$$Ag_4P_2O_7 + 2H_2S = 2Ag_2S + H_4P_2O_7.$$

Sulphide of silver and pyrophosphoric acid result.

Tests.—Nitrate of silver gives a *white* precipitate, but no precipitate is caused by albumen and acetic acid.

From the description of the foregoing substances, it will be seen that there are three distinct forms of phosphoric acid—the meta, the pyro, and the tribasic, or orthophosphoric. Their modes of preparation have been already described, but they may also be prepared by acting upon phosphoric anhydride (P_2O_5) by different proportions of water (H_2O) as follows:

PHOSPHORIC ACIDS.

$P_2O_5 + H_2O = 2HPO_3$ Metaphosphoric acid.
$P_2O_5 + 2H_2O = H_4P_2O_7$ Pyrophosphoric acid.
$P_2O_5 + 3H_2O = 2H_3PO_4$ Orthophosphoric acid.

It may also be shown that by heating the tribasic phosphate ($2H_3PO_4$) and thus driving off a molecule of water, we can obtain the pyrophosphoric acid ($H_4P_2O_7$), and by the action of heat upon this, with the loss of another molecule of water, we obtain the metaphosphoric acid ($2HPO_3$).

PHOSPHORUS WITH HYDROGEN forms three compounds, to all of which the name of phosphuretted hydrogen is applied, viz.:

Tri-hydride of phosphorus, PH_3
Di-phosphorus tetra-hydride, P_2H_4 } Phosphuretted hydrogens
Tetra-phosphorus di-hydride, P_4H_2

PH_3, tri-hydride of phosphorus, is a colourless gas possessing a powerful garlic-like odour, and burning with a brilliant white flame, with the formation of water and P_2O_5.

Preparation.—(1) By heating phosphorous acid. Thus—

$$4H_3PO_3 + \text{heat} = 3H_3PO_4 + PH_3.$$

Tribasic phosphoric acid and trihydride of phosphorus result.

(2) By the action of caustic potash (KHO) upon phosphorus (P) and water (H_2O). Thus—

$$3KHO + 4P + 3H_2O = 3KH_2PO_2 + PH_3.$$

Potassium hypophosphite and tri-hydride of phosphorus result.

This gas is prepared under water, but as each bubble rises, it takes fire spontaneously in contact with the air, forming white rings of phosphorus pentoxide (P_2O_5) expanding as they rise. When perfectly pure, this PH_3 is not spontaneously combustible, but is usually so from the presence of the following compound:

P_2H_4. Di-phosphorus tetra-hydride is a colourless, very volatile liquid, of high refractive power, and spontaneously inflammable. It can be prepared by passing PH_3 through a tube cooled by a freezing mixture.

P_4H_2. Tetra-phosphorus di-hydride is a solid substance, and is prepared by passing P_2H_4, the liquid hydride, into hydrochloric acid (HCl); tri-hydride of phosphorus and tetra-phosphorus di-hydride resulting.

P_4H_2 precipitates gold and silver from their solutions, but does not affect the salts of lead.

PHOSPHORUS WITH CHLORINE forms two compounds, viz.:

PCl_3. Phosphorous chloride, phosphorus trichloride.
PCl_5. Phosphoric chloride, phosphorus pentachloride.

Phosphorous chloride, PCl_3, is a colourless, volatile, strongly fuming liquid, and is formed by passing chlorine gas over phosphorus. It gradually decomposes into hydrochloric acid, and phosphorous acid. It may also be formed by the spontaneous combustion of phosphorus in chlorine gas.

Phosphoric chloride, PCl_5, is a solid crystalline body, and decomposes by excess of water into hydrochloric acid (HCl), and tribasic phosphoric acid (H_3PO_4). It is prepared by passing excess of chlorine through the phosphorous chloride. Should water be present only in limited quantity, a liquid called *phosphorus oxy-chloride*, PCl_3O, is formed. Thus—

$$PCl_5 + H_2O = 2HCl + PCl_3O.$$

By bringing together nitrate of silver ($AgNO_3$), and PCl_3O. Thus—

$$3AgNO_3 + PCl_3O = Ag_3PO_4 + 3NO_2Cl.$$

Phosphate of silver, and nitroxyl chloride are formed.

Phosphorus forms with Iodine PI_3 and PI_5, with Bromine PBr_3, and PBr_5, and it burns spontaneously in those bodies. By the action of sulphuretted hydrogen (H_2S) upon phosphoric chloride, PCl_5—a substance termed phosphoric sulphochloride, $PSCl_3$, is obtained.

Phosphorus forms several compounds with sulphur, two of them, P_2S_3 and P_2S_5, corresponding in composition with the oxides P_2O_3, and P_2O_5.

ARSENIC—Arsenicum—(arsenicon, orpiment).

Symbol, As. Combining weight, 75. Vapour density, 150.

The volume occupied by an atom of this substance (in the gaseous state), weighing 75, is only ½ of that occupied by the other elements generally; arsenic, therefore, in this respect resembles phosphorus.

Description.—This substance closely resembles phosphorus in its chemical properties and in its modes of combination, but in its physical characters it presents a strong analogy to the metals; a triad element; rarely or never occurring native, being usually found in combination as mispickel (FeAsS), a compound of iron, arsenic, and sulphur; tin-white cobalt ($CoAs_2$), cobalt and arsenic; cobalt-glance (CoSAs), cobalt, sulphur, and arsenic; nickel-glance (NiSAs), nickel and arsenic; kupfer-nickel (NiAs), nickel and arsenic; arsenical nickel ($NiAs_2$), nickel and arsenic. It is also contained in very small quantities in many mineral springs.

Preparation.—By heating the arsenic tri-oxide (As_2O_3)

mixed with charcoal (C) in a closed crucible, of which the upper part is kept cool. Thus—

$$As_2O_3 + 3C = 3CO + 2As.$$

Carbonic oxide and arsenicum are formed, the latter of which condenses at the upper part of the apparatus as a brilliant steel-grey solid. When exposed to the air, arsenicum tarnishes by oxidation. Its specific gravity is 5·7. Heated to dull redness it entirely volatilizes, without fusion, as a colourless vapour having the odour of garlic.

If heated in the air, As burns with a bluish flame, forming As_2O_3, arsenic tri-oxide.

ARSENIC WITH OXYGEN forms two compounds, viz.:

As_2O_3—Arsenic tri-oxide, arsenious anhydride.
As_2O_5—Arsenic pent-oxide, arsenic anhydride.

ARSENIC TRIOXIDE. ARSENIOUS ANHYDRIDE.

Symbol, As_2O_3. Molecular weight, 198.

Description.—This substance occurs in two modifications, viz.:

(1) The *Crystalline*, in brilliant octahedra.

(2) The *Vitreous*, without crystalline structure; a semi-transparent glass-like solid, becoming opaque, like porcelain, upon standing.

Preparation.—(1) By burning arsenicum (As) in air.

(2) By roasting arsenical ores and purifying by sublimation; As_2O_3 is very feebly soluble in cold water, and, even in boiling water, has a tendency to float in film. With water, arsenious anhydride forms arsenious acid (H_3AsO_3). Thus—

$$As_2O_3 + 3H_2O = 2H_3AsO_3.$$

This acid has a feeble reaction, and dissolves in hydrochloric acid; it is freely soluble in solutions of the alkalies, forming arsenites. All these soluble arsenites are poisonous.

If As_2O_3 be heated to about 220°C, it volatilizes without melting, forming a colourless, inodorous vapour.

The tests for arsenious acid may be divided into three groups:

(1) Solid; (2) Liquid, and (3) Special.

The solid tests are two in number:

(1) Arsenious acid, when heated upon charcoal, emits an odour of garlic.

(2) As_2O_3 is heated in a reduction tube with black flux, *i.e.*, dried carbonate of soda and charcoal. Metallic As is formed, and condenses as a ring upon the cool part of the tube.

The liquid tests are three:

(1) Sulphuretted hydrogen (H_2S) gives a *yellow* precipitate of sulphide of arsenic (As_2S_3) soluble in ammonia.

(2) Ammonio-nitrate of silver, made by adding just enough liquor ammoniæ to the nitrate of silver to precipitate the brown oxide of silver (Ag_2O), gives a canary yellow precipitate of arsenite of silver (Ag_3AsO_3), soluble in excess of ammonia.

(3) Ammonio-sulphate of copper, made by adding to a solution of sulphate of copper just enough liquor ammoniæ to throw down a pale-blue precipitate, gives a *green* precipitate of arsenite of copper or Scheel's green ($CuHAsO_3$), soluble in excess of ammonia.

The special tests are two:

(1) Marsh's test. This consists in the decomposition of arsenious acid by means of nascent hydrogen. A suitable vessel is taken, and in it are placed some strips of zinc with water and sulphuric acid. Hydrogen is thus generated, and escapes through a gas-jet with which the vessel is furnished. This gas burns with a very faintly luminous flame when a light is applied, the result of its combustion being only a few drops of water. The arsenious acid is now added to the contents of the vessel. The hydrogen flame is converted into arseniuretted hydrogen (AsH_3), and burns with a *pale-blue* flame. A white porcelain plate is now placed over this last flame, and a deposit is formed which may be divided into three rings. Thus:

(*a*) A central ring, consisting of metallic arsenic, (*b*) a ring round this, consisting of a mixed deposit of As and As_2O_3, and (*c*) an external ring of As_2O_3. This deposit is soluble in a solution of chlorinated lime.

(2) Reinsch's test. This consists in boiling bright strips of copper in an arsenical solution previously acidulated by hydrochloric acid. The metal arsenicum becomes deposited upon the strips of copper, which are then withdrawn and placed in a reduction tube, with the same result as has been described above under the solid tests.

Arsenic Pentoxide. Arsenic Anhydride.

Symbol, As_2O_5. Molecular weight, 230.

Description.—A white deliquescent non-crystalline powder, decomposing when strongly heated into arsenious anhydride (As_2O_3) and oxygen (O).

Preparation.—By acting upon As_2O_3 with strong nitric acid (HNO_3). Thus—

$$As_2O_3 + 2HNO_3 = H_2O + N_2O_3 + As_2O_5.$$

Water, nitrogen trioxide, and arsenic anhydride are formed.

As_2O_5 dissolves in water, and forms arsenic acid, H_3AsO_4. Thus—

$$As_2O_5 + 3H_2O = 2H_3AsO_4.$$

This acid may be also prepared by the action of diluted nitric acid upon As_2O_3. Thus—

$$As_2O_3 + 2H_2O + 2HNO_3 = N_2O_3 + 2H_3AsO_4.$$

Nitrogen trioxide, and arsenic acid are formed.

With ammonio-nitrate of silver, arsenic acid gives a *chocolate-red* precipitate of arseniate of silver.

H_3AsO_4 is a poison, but less energetic than H_3AsO_3.

ARSENIC WITH CHLORINE forms

ARSENIOUS CHLORIDE, $AsCl_3$.

This substance can be prepared—(1) By the combustion of arsenicum in chlorine gas, or (2), by distilling As with mercuric chloride ($HgCl_2$). Thus—

$$4As + 12HgCl_2 = 12HgCl + 4AsCl_3.$$

Mercurous chloride and arsenious chloride are formed.

Corresponding compounds with bromine ($AsBr_3$), iodine (AsI_3), and fluorine (AsF_3), are also known.

ARSENIC WITH HYDROGEN forms

ARSENIURETTED HYDROGEN, AsH_3.

This gas has been, to some extent, described under Marsh's test. Its preparation may be expressed as follows :—

$$6Zn + 6H_2SO_4 + As_2O_3 = 6ZnSO_4 + 3H_2O + 2AsH_3.$$

Zinc, sulphuric acid, and arsenious anhydride yield sulphate of zinc, water, and arseniuretted hydrogen.

ARSENIC WITH SULPHUR forms three compounds :

(1) Di-arsenicum di-sulphide, As_2S_2, occurring native in ruby-red crystals, as "Realgar."

(2) Arsenious sulphide, As_2S_3, called also "sulph-arsenious anhydride," and occurring native as a yellow solid or "orpiment."

(3) Arsenic sulphide, As_2S_5, or "sulph-arsenic anhydride;" a yellow substance obtained by fusing sulphur (S_2) with As_2S_3.

A general chemical analogy between nitrogen, phosphorus and arsenic, will be observed in the examination of their oxides, hydrides and chlorides, viz.:

N_2O_3	P_2O_3	As_2O_3.
N_2O_5	P_2O_5	As_2O_5.
NH_3	PH_3	AsH_3.
NCl_3?	PCl_3	$AsCl_3$.

BORON (Baurak, *Arabian*, Borax).

Symbol, B. Combining weight, 11.

Description.—A triad element; never native; is found united with oxygen and sodium, as borax; and with oxygen alone as boron trioxide; occurs in three modifications—

(1) *Amorphous boron*, a dull grey powder, which when strongly heated in air burns to boric oxide (B_2O_3).

Prepared by heating the fused boron trioxide (B_2O_3) with metallic sodium (Na). Thus—

$$B_2O_3 + 6Na = 3Na_2O + 2B.$$

Soda and (amorphous) boron result.

(2) *Graphitoidal boron*, in scales with graphite-like lustre.

Prepared by heating boron trichloride (BCl_3), with aluminium (Al). Thus—

$$2Al + 2BCl_3 = 2AlCl_3 + 2B.$$

Chloride of aluminium and (graphitoidal) boron result.

(3) *Diamond boron*, in square octahedra of cupreous lustre; hard enough to scratch a ruby.

Prepared by heating boron trioxide (B_2O_3) with aluminium (Al). Thus—

$$B_2O_3 + 2Al = Al_2O_3 + 2B.$$

Alumina and (diamond) boron result.

Boron, when heated strongly in chlorine or oxygen, takes fire, forming the chloride or oxide. It is remarkable for uniting directly with nitrogen, which gas it absorbs when red hot with the evolution of light, forming—

Boron Nitride.

Symbol, BN.

This is a grey mass, and may also be prepared by heating biborate of soda or borax ($Na_2B_4O_7$) with chloride of ammonium (NH_4Cl). Thus—

$$Na_2B_4O_7 + 4NH_4Cl = 2NaCl + 2HCl + 7H_2O + 4BN.$$

Chloride of sodium, hydrochloric acid, water, and boron nitride are formed.

Boron with Chlorine forms a liquid called

Boron Tri-Chloride

Symbol, BCl_3.

Prepared from boron trioxide (B_2O_3), chlorine (Cl), and carbon (C), at a bright red heat. Thus—

$$B_2O_3 + 6Cl + 3C = 3CO + 2BCl_3.$$

Carbon monoxide and boron trichloride result.

BORON WITH FLUORINE forms
BORON TRI-FLUORIDE.

Symbol, BF_3.

An irritating, colourless, irrespirable gas, fuming in air; with water it forms—

HYDRO-FLUO-BORIC ACID.

Symbol, HBF_4.

Thus—

$$4BF_3 + 3H_2O = H_3BO_3 + 3HBF_4.$$

Boracic acid and hydro-fluo-boric acid result.

BORON WITH OXYGEN forms

BORON TRIOXIDE. BORACIC ANHYDRIDE.

Symbol, B_2O_3. Molecular weight, 70.

This fuses to a glass, which retains its clearness on cooling. It is prepared by heating boracic acid (H_3BO_3). Thus—

$$2H_3BO_3 = 3H_2O + B_2O_3.$$

Water and boron trioxide result.

WITH WATER B_2O_3 forms

BORIC OR BORACIC ACID.

Symbol, H_3BO_3. Molecular weight, 62.

Description.—A tribasic acid, crystallising in pearly plates from the solution as it cools.

Found in the fumerolles or soffioni (steam jets), which are constantly escaping from the earth in old volcanic districts of Tuscany, and which collect in the lagoons at the mouth of these jets. The boracic acid is concentrated by the heat of the natural steam jets, and the acid obtained by crystallisation.

Tinkal or sodium borate (Na_2BO_3) also occurs in California and Thibet.

A solution of H_3BO_3 in alcohol, when ignited, communicates a green colour to the flame.

Boracic acid also gives a red colour to turmeric.

This acid is slightly soluble in cold water, but rather more so in hot water.

Boracic acid may also be prepared by the addition of hydrochloric acid (HCl) to a hot solution of borax ($Na_2B_4O_7$). Thus—

$$Na_2B_4O_7 + 2HCl + 5H_2O = 2NaCl + 4H_3BO_3.$$

Chloride of sodium and boracic acid result.

BORAX. BIBORATE OF SODA.

Symbol, $Na_2B_4O_7$, $10H_2O$.

As has been stated above, this substance is a compound of sodium, boron and oxygen. It is a native salt, but can be artificially prepared by heating together boracic acid (H_3BO_3) and carbonate of soda (Na_2CO_3). Thus—

$$4H_3BO_3 + Na_2CO_3 = 6H_2O + CO_2 + Na_2B_4O_7.$$

Water, carbonic anhydride, and borax result.

Borax is much used as a blow-pipe re-agent in the laboratory, since many metallic oxides are soluble in fused borax, yielding coloured glasses as follows:

BORAX BEADS.

		Oxidizing, or Outer Flame.		*Reducing, or Inner Flame.*	
		Hot.	*Cold.*	*Hot.*	*Cold.*
Chromium	(Cr)	Green	Green	Green	Green.
Cobalt	(Co)	Blue	Blue	Blue	Blue.
Nickel	(Ni)	Violet	Reddish-brown	Colourless	Grey and turbid.
Copper	(Cu)	Green	Blue	Colourless	Brownish-red from MetallicCu.
Iron	(Fe)	Brownish-red	Light yellow	Red (Yellowish	Bottle-green on cooling)
Manganese	(Mn)	Amethyst-red or violet	Amethyst-red	Colourless (but not	Colourless quite clear)
Silver	(Ag)	Yellowish to opal	Rather dull	Colourless	Whitish-grey.
Gold	(Au)	Are reduced in all flames, the Au showing blueish-green by transmitted light, and reddish by reflected.			
Platinum	(Pt)				

SILICON—(Silex, a flint).

Symbol, Si. Combining weight, 28.

Description.—A tetrad element; never native, but combined with oxygen as silica (SiO_2). Exists nearly pure in rock crystal or quartz, in sand, flint, and many minerals; also found combined with the metals and oxygen, as silicates. The most abundant element known next to oxygen. There are three modifications of silicon, viz.:

(1) *Amorphous silicon.*—A brown powder, only acted upon by hydrofluoric acid (HF), which dissolves it.

Prepared by acting upon silico-fluoride of potassium ($(KF)_2,SiF_4$) with metallic potassium (K). Thus—

$$(KF)_2,SiF_4 + 4K = 6KF + Si.$$

Fluoride of potassium, and (amorphous) silicon result.

(2) *Graphitoidal silicon.*—Hexagonal plates with metallic lustre.

Prepared by fusing the amorphous form with aluminium (Al), and dissolving the latter in hydrochloric acid.

(3) *Adamantine silicon,* in steel-grey crystals, hard enough to scratch glass. Prepared by heating aluminium (Al), in the vapour of silicon tetrachloride ($SiCl_4$). Thus—

$$3SiCl_4 + 4Al = 2Al_2Cl_6 + 3Si.$$

Chloride of aluminium and (adamantine) silicon result.

SILICON WITH OXYGEN forms

SILICIC ANHYDRIDE. SILICON DIOXIDE. SILICA.

Symbol, SiO_2. Molecular weight, 60.

Description.—A snow-white, gritty, insoluble powder-almost infusible, but soluble in hydrofluoric acid (HF). Prepared by heating metasilicic acid (H_2SiO_3). Thus—

$$H_2SiO_3 + \text{heat} = H_2O + SiO_2.$$

Water and silica are formed.

SiO_2 also exists in a crystallised form, as white transparent quartz.

SILICA WITH WATER
forms two acids, viz.:

(1) Meta-silicic acid ($SiO_2 + H_2O = H_2SiO_3$).
(2) Ortho-silicic acid ($SiO_2 + 2H_2O = H_4SiO_4$).

META-SILICIC ACID.

Symbol, H_2SiO_3.

Description.—A clear limpid fluid, with a tendency to become gelatinous.

The chief agent in petrifaction.

Preparation.—By acting upon potassium silicate (K_2SiO_3), by hydrochloric acid (HCl) and heat. Thus—

$$K_2SiO_3 + 2HCl = 2KCl + H_2SiO_3.$$

Chloride of potassium, and meta-silicic acid are formed. This acid must be prepared by

DIALYSIS.

By this term is implied a process used in chemistry for the separation of bodies. It is dependent upon the fact that all

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Chloride of sodium and boracic acid result.

BORAX. BIBORATE OF SODA.

Symbol, $Na_2B_4O_7$, $10H_2O$.

Selenium Dioxide.

Symbol, SeO_2. Molecular weight, 111·5.

Description.—A white, crystalline mass, soluble in water. It may be prepared by burning selenium in air, or oxygen, or by the oxidation of this substance by nitric acid.

Selenious Dioxide with Water forms

Selenious Acid.

Symbol, H_2SeO_3.

A powerful acid, resembling sulphurous acid.

Selenium Trioxide.

Symbol, SeO_3.

Has never been isolated, but an acid is known called—

Selenic Acid.

Symbol, H_2SeO_4.

This acid resembles sulphuric acid. In the reducing flame of the blow-pipe it emits the odour of selenium. It is a solvent of gold, but not of platinum.

Preparation.—By the addition of sulphuretted hydrogen (H_2S), to selenate of lead ($PbSeO_4$). Thus—

$$PbSeO_4 + H_2S = PbS + H_2SeO_4.$$

Sulphide of lead is formed, and upon evaporating the solution, selenic acid is left.

Selenium with Hydrogen forms

Hydrogen Selenide. Seleniuretted Hydrogen.

Symbol, H_2Se. Molecular weight, 81·5. Density, 40·75.

Description.—A colourless, inflammable gas, with a nauseous smell, exciting catarrh, and destroying the sense of smell. Decomposes metallic solutions, like sulphuretted hydrogen.

Preparation.—From selenide of iron ($FeSe$), by the action of sulphuric acid (H_2SO_4). Thus—

$$FeSe + H_2SO_4 = FeSO_4 + H_2Se.$$

Sulphate of iron, and seleniuretted hydrogen result.

TELLURIUM—(Tellus, the earth).

Symbol, Te. Combining weight, 129. Density, 129.

Description.—A very rare substance of silvery, metallic appearance, and brittle. Is found combined with gold, silver, and bismuth, in Transylvania and Hungary. When administered internally, it communicates to the breath a garlic odour.

Tellurium dissolves in cold concentrated sulphuric acid, to which it imparts a fine purple colour. It forms with oxygen two oxides:

(1) TELLURIUM DIOXIDE.

Symbol, TeO_2.

Formed when tellurium is oxidised by nitric acid.

TeO_2, with water, forms TELLUROUS ACID (H_2TeO_3).

(2) TELLURIUM TRIOXIDE.

Symbol, TeO_3.

Forms, with water, TELLURIC ACID, $H_2TeO_4 + 2H_2O$.

TELLURIUM WITH HYDROGEN forms

TELLURETTED HYDROGEN.

Symbol, H_2Te.

A colourless gas, smelling exactly like sulphuretted hydrogen.

It will be noticed that oxygen, sulphur, selenium, and tellurium, each unite with two atoms of hydrogen, to produce an analogous series of bodies, viz.:

$$H_2O\,;\ H_2S\,;\ H_2Se\,;\ H_2Te.$$

And of the three, sulphur (32), selenium (79·5) and tellurium (129), the mean of the combining weight of the extremes is nearly that of the mean, viz.:

$$\frac{32 + 129}{2} = 80{\cdot}5.$$

Their specific gravities exhibit a similar gradation, viz.:
Sulphur, 2·0; Selenium, 4·5; Tellurium, 6·25.

THE METRIC SYSTEM OF WEIGHTS AND MEASURES.

The *metre* is a unit of length, equal to a little more than one yard, viz., 39·37 English inches. Its length is arbitrary, but a standard metre has been prepared, and of this copies are in use. The French geometricians first intended that the length of this metre should have some reference to the circumference of the earth, and they therefore caused a standard to be made, having the length of the $\frac{1}{10000000}$ of the distance from the equator to the pole. It has been subsequently proved that the metre is not quite, although very nearly, the $\frac{1}{10000000}$ part of this distance.

The metre is divided into tenths, *decimetres*, hundredths, *centimetres*, and thousandths, *millimetres*. The multiples of the metre, tens, hundreds, and thousands, are termed *decametres*, *hectometres*, and *kilometres* respectively.

We can easily obtain the measures of *area* and *capacity*, and thus we have *square* metres, and *square* deci-, centi-, and milli- metres; and also *cubic* metres and *cubic* deci-, centi-, and milli- metres.

10 decimetres	... ...	1 metre.
100 centimetres	... ...	,,
1,000 millimetres	... ...	,,
100 square decimetres	...	1 square metre.
10,000 ,, centimetres	...	,,
1,000,000 ,, millimetres	...	,,
1,000 cubic decimetres	... ...	1 cubic metre.
1,000,000 ,, centimetres	...	,,
1,000,000,000 ,, millimetres	...	,,

The *litre* is a term used to denote 1 cubic decimetre, which is rather less than a quart English. It is divided into 10ths deci-, 100ths centi-, 1000ths milli- litres; a decalitre = 10 litres, a hectolitre = 100 litres; a kilolitre = 1000 litres.

The arrangers of this system were desirous of obtaining a simple relation between the measure of volume and that of weight, and they therefore took as their unit of weight *the weight of* 1 *cubic centimetre* of water at the temperature of 4° centigrade, and they called this a *gramme*. It is equal to about 15½ grains. Like the metre, this gramme is divided into tenths, hundredths, and thousandths, called deci-, centi-, and milli- grammes; the multiples, tens, hundreds, and thousands are called deca-, hecto-, and kilo- grammes.

MEASUREMENT OF TEMPERATURE.

We ascertain the measurements of changes of temperature by the expansion or contraction which bodies undergo by alternations of temperature. Liquids are generally used for this purpose, since gases expand too much, and solids too little. We commonly employ alcohol and mercury, especially the latter, since its rate of expansion is almost uniform within a certain range, and because it boils at a very high temperature (350°C), and freezes at a comparatively low one (-39·4°C), and is therefore capable of measuring a large range of temperature. We use alcohol for the measurement of very low temperatures, since it has never been frozen. It is only in very delicate experiments in physics that air thermometers are employed.

The Mercurial Thermometer.

To prepare this, a straight piece of glass-tubing is taken, with as uniform a bore as possible, and a bulb is blown upon the end. The bulb and the whole of the tube are filled with mercury, and heated to the highest temperature we require to measure. The open end of the tube, full of mercury, is then completely closed, the glass being melted before the blowpipe. We now have *to graduate* the thermometer, and this is performed as follows:

(1) The bulb and stem are plunged *into finely powdered melting ice*, and the stem marked at the point where the mercury stands.

(2) The bulb and stem are immersed *in the steam given off from water boiling in a metallic vessel*, and the stem marked where the mercury then stands.

There are three thermometric scales at present in use, each of which can be expressed in terms of the other, viz.:

1. Centigrade.
2. Fahrenheit.
3. Réaumur.

In the *Centigrade* scale, the zero is placed at the freezing point, and the boiling point at 100°, so that between these two points there are 100 *degrees*. Above the boiling and below the freezing points divisions equal in size are continued, those below the freezing point being distinguished by a minus sign, viz., -1°C, -2°C, etc.

In the *Fahrenheit* scale the freezing point is fixed at 32°, and the boiling point at 212°, so between these points there are 180 degrees.

In the *Réaumur* scale we have 80° between the boiling and freezing points. The freezing point is zero, and the boiling point 80°.

The numbers 9, 5, 4 consequently express the relation between degrees Fahrenheit, Centigrade and Réaumur. Now, 180° Fahrenheit equals 100° Centigrade, *i.e.*, $1°F = (\frac{100}{180})\ \frac{5}{9}\ C$; and $1°C = (\frac{180}{100})\ \frac{9}{5}\ F$. We therefore multiply Fahrenheit degrees by $\frac{5}{9}$ to reduce them to Centigrade, and Centigrade degrees by $\frac{9}{5}$ to reduce them to Fahrenheit. But while on the Centigrade scale the zero is at the freezing point of water, on the Fahrenheit scale it is at 32°. We must therefore add or subtract 32, according to circumstances, in order to obtain the same starting point. In short:

(1) In converting Fahrenheit into Centigrade degrees, subtract 32 from the number of the degrees, and multiply the remainder by $\frac{5}{9}$, thus:

Alcohol boils at 173° F; what is this on the Centigrade scale?

$$173 - 32 = 141\ ;\ \text{and}\ 141 \times \tfrac{5}{9} = 78{\cdot}3°C.$$

(2) In converting Centigrade to Fahrenheit degrees, multiply the number of degrees by $\frac{9}{5}$, and add 32 to the product, thus:

Mercury freezes at -39·4°C; what is this on the Fahrenheit scale?

$$-39{\cdot}4 \times \tfrac{9}{5} = -70{\cdot}9\ ;\ \text{and}\ -70{\cdot}9 + 32 = -38{\cdot}9°F.$$

EXPANSION OF GASES BY HEAT.

Gases expand much more for equal increments of heat than solids or liquids; all gases expand alike or nearly so, while solids and liquids all expand differently. Exact and laborious experiments have shown that all gases expand $\frac{1}{273}$ part of their volume at 0°C for every increase in temperature of 1° Centigrade.

	273	volumes of air or Hydrogen	at 0°C.	
Become	274	,,	,,	1°C.
,,	275	,,	,,	2°C.
,,	276	,,	,,	3°C.
Or	273 + t	,,	,,	t°C.

The corresponding decimal fraction to $\frac{1}{273}$ is 0·003,665; 1 volume of air at 0°C becomes 1·003,665 volumes when heated to 1°C. The *co-efficient of the expansion of gases* is the name given to this fraction. Suppose we wish to know the volume which 1000 cubic centimetres of H measured at 0°C will occupy

when the temperature is raised to 20°, we have an alteration in bulk in the ratio of the numbers 273 to 273 + 20. We therefore multiply 1000 by 293, and divide by 273. Should we wish to know what volume 1000 cubic centimetres, measured at 20°C, will occupy when the temperature sinks to 0°, we know that diminution in volume follows the same law; therefore, 293 volumes at 20° will become 273 volumes at 0°.

RELATION OF VOLUME OF GASES TO PRESSURE.

Gases are known as *compressible bodies*, because when they are subjected to pressure their volume becomes less, and upon the withdrawal of the pressure they again expand. Solids and liquids cannot be compressed in the same way, and are hence called *incompressible*. Boyle's or Mariotte's law states that *the volume occupied by any gas is inversely proportional to the pressure to which it is subjected.* The volume 1 under pressure 1 becomes the volume 2 under the pressure $\frac{1}{2}$, the volume 3 under the pressure $\frac{1}{3}$, the volume $\frac{1}{2}$ under the pressure 2, and the volume $\frac{1}{3}$ under the pressure 3, and so on.

DIFFUSION OF GASES.

When gases are mixed together, and do not combine chemically, they have the power of becoming intimately mixed together, even when the heavier gas is placed at the bottom, and both remain undisturbed. This property illustrates the *diffusive power of gases.* The rate of diffusion is subject to variation. A bottle of carbonic acid lost only 47 per cent. of gas when left exposed to the air in the same time that a bottle of hydrogen lost 94·5 in the same way. Gaseous diffusion will take place through such solids as stucco, or thin plates of graphite. Experiments show that *the velocity of diffusion of different gases is inversely proportional to the square roots of their densities;* oxygen being 16 times as heavy as hydrogen, 4 volumes of the latter will pass through the diaphragm in the same time that one volume of the former will be able to do so.

FINIS OF PART I.

TABLE OF QUANTIVALENCE OF THE NON-METALLIC ELEMENTS.

Monads.	*Dyads.*	*Triads.*	*Tetrads.*
Hydrogen	Oxygen	Nitrogen	Carbon
Chlorine	Sulphur	Phosphorus	Silicon
Bromine	Selenium	Boron	
Iodine	Tellurium	Arsenic	
Fluorine			

INDEX.